Agricultural management practices for improved water quality in the Canadian Great Lakes Basin

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PREFACE

The interaction of agricultural land use and the environment has become a topic of concern to many. In 1972 the International Joint Commission (IJC) established the Land Use Activities Reference Group, the forerunner of the Pollution from Land Use Activities Reference Group (PLUARG), to determine the effects of land drainage on water quality. Participants from both Canada and the United States were involved. Agriculture Canada was represented in this group and assisted in drawing up a detailed study plan for the Agricultural Watershed Studies, while many of the actual studies were carried out by Agriculture Canada scientists. Coordination and implementation of the program was a joint endeavour of the Ontario Ministry of Agriculture and Food, Ontario Ministry of Environment and Agriculture Canada. The various individual reports and summaries are listed in a Bibliography published by the IJC (Anonymous 1979a).

The IJC agreed, in general, with PLUARG's conclusion that the Great Lakes were being polluted by land drainage and that agriculture, especially intensive operations, were involved. They suggested that there was a need for better public knowledge, involvement and action towards the problem of Great Lakes pollution. Before the public can voluntarily institute measures for the reduction of non-point pollution they must be aware of local problems and their impact on the Great Lakes ecosystem. The successful implementation of remedial measures will depend on the awareness and co-operation of land users and on the skill and knowledge of field personnel at the local level. Although there is a large volume of research information available on the effects of farm level decisions on water quality, it is not usually readily accessible to potential users at the local level. Problems related to the environment are likely to increase as rising domestic and world demands for food and fibre lead to increased production demands. More intensive management of our limited agricultural base will be necessary, and will likely entail greater use of both chemicals and marginal farmland. Development of cropping systems that both sustain crop production and protect and/or improve the quality of our environment will be required.

As part of Agriculture Canada's follow-up program to the PLUARG studies, the Land Resource Research Institute is involved in gathering together available information on the interactions between agriculture and the environment. This report was designed to present current information on the effects of farm management decisions on water quality in a readily available format for those involved in agricultural land use planning and remedial measures programs. It is hoped that this report will contribute to the development of sound farm management options which will protect and maintain not only the farm production capabilities but local water quality as well.

SUMMARY

Research in the Great Lakes Basin has established that agriculture contributes sediment, nutrients and agricultural chemicals to the drainage network at levels higher than those accounted for by natural processes and that ultimately a proportion of these pollutants reaches the Great Lakes. The problems and solutions of agricultural non-point pollution are very site specific, and highly dependant on land management and its interaction with varying weather conditions.

Detailed analysis of agricultural watersheds has shown that sediment and total phosphorus have the most serious pollution effects, for both the Great Lakes and local water quality. The location and size of a contributing area is a variable dependent on the time of year, local weather conditions and management practices. Soil texture is an important indication of pollution potential. Fine-grained soils produce more overland runoff (because of reduced infiltration), are easily transported (because they are easily suspended but settle out slowly), and generally carry more associated pollutants (because of the sorption capacity of clay particles). Increased intensity of cultivation (i.e. area cultivated and/or degree of cultivation) is also an important factor in increasing pollution loads from agricultural land. Other pollutants from agricultural drainage (i.e., nitrates, pesticides and heavy metals) do not appear to be a Great Lakes water quality problem although local contamination was considered possible.

In many cases the agricultural contribution to water quality deterioration can be reduced significantly without a major reduction in farm income. Improved management of farm lands, livestock operations and usage of materials is required. Improved land management measures include practices such as conservation tillage, increased use of surface residues, crop rotations, contour cropping, strip cropping, terraces, grassed waterways, runoff diversions and improved drainage outlets. Livestock management practices which protect water quality centre on reducing direct nutrient input to streams from manure and include proper manure and runoff containment and storage facilities, exclusion of livestock from streams and disposal of manure according to recommended procedures. Losses of agricultural chemicals can be diminished by reducing their presence at the soil surface through elimination of excess use, modification of timing and application procedures and incorporation of the chemicals where possible.

Farmers must be aware of the impact they can have on water quality and of the management alternatives available to them for preventing water pollution so that they can adopt practices which reduce agriculturally related problems, both within the Great Lakes and locally.

Résumé

La recherche entreprise dans la région des Grands Lacs a démontré que l'agriculture contribue à l'apport de sédiments, d'éléments nutritifs et de substances toxiques dans les eaux des Grands Lacs, et que ces polluants sont plus importants que ceux produits par des processus naturels. Les problèmes et les solutions varient d'un endroit à l'autre et dépendent fortement des pratiques de gestion des terres et de leurs interactions avec les conditions climatiques.

L'analyse des données rassemblées dans les bassins hydrographiques agricoles démontre que les sédiments et le phosphore sont les polluants les plus importants. Les zones de ruissellement varient en dimensions et en intensités selon la saison, les conditions climatiques et les pratiques culturales. La texture du sol est un bon indicateur de son pouvoir polluant. Les sols argileux occasionnent un ruissellement abondant (à cause du faible taux d'infiltration de l'eau), ces sédiments se déplacent facilement (la capacité à rester en suspension), et transportent une grande quantité de matières polluantes (la capacité d'absorption des particules argileuses). L'agriculture intensive (i.e. superficie cultivée et/ou la fréquence des cultures) est un autre facteur important qui augmentera la pollution. D'autres polluants (les nitrates, les pesticides et les métaux lourds) ne semblent pas encore un problème sérieux pour la qualité de l'eau des Grands Lacs, toutefois certains endroits possèdent un fort potentiel.

Dans plusieurs cas, la réduction de la pollution des eaux par l'agriculture peut se faire sans coûts prohibitifs pour les agriculteurs. L'amélioration de la gestion des terres et des parcs à bestiaux s'avèrent nécessaire. Les mesures pour l'amélioration de la gestion des terres sont les suivantes: utilisation de paillis, pratiquer un labour minimal nécessaire pour la culture, la rotation des cultures, cultiver perpendiculairement à la pente, construire des terres-pleins, culture en bandes, culture en terrasses et améliorer les voies de drainage. Les pratiques de gestion du bétail qui protègeraient la qualité de l'eau sont basées sur la diminution des contacts directs entre les fumiers et les bestiaux avec les eaux des cours d'eaux, sur l'amélioration des fosses pour l'emmagasinage du fumier et sur l'epandage du fumier selon les méthodes recommendées. Pour réduire la contamination de l'eau par les substances chimiques, on peut diminuer leurs emplois excessifs, contrôler les doses et adapter un calendrier d'application selon les besoins réels, et favoriser l'incorporation de ces substances dans le sol.

Les cultivateurs doivent comprendre les effets de ces substances sur la qualité des eaux et des moyens pour en prévenir la pollution. Ainsi, ils pourront adopter les pratiques de gestion qui diminueront la pollution agricole dans les cours d'eaux avoisinants et dans les Grands Lacs.

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1. INTRODUCTION

Public concern for ecological and environmentally related issues has been increased in recent years by the environmental movement. Obvious problems such as water contamination from sewage discharge and industrial effluent were the initial concerns, however the focus is now shifting to "nonpoint" sources of pollutants, i.e. pollutants without a localized point of origin. Because agriculture occupies a large land-base it is able to exert a great influence on the environment. Whether this impact is positive or negative will depend on the farmer and his approach to land management.

Technological advances have allowed farmers to work larger areas and obtain higher yields than ever before. Improved varieties, chemical fertilizers and extensive drainage and irrigation projects have enabled farmers to grow crops on land that was once considered uneconomical to farm. Increased value of crops such as corn, soybeans and white beans has encouraged intensive use of wide-row cropping in the last 20 years, greatly reducing and sometimes eliminating crop rotations. Large multirow equipment and government incentives have led to removal of fence rows and increased field size, making erosion control measures such as contour cropping and terracing more necessary but less attractive (Wadleigh 1971; Laflen and Moldenhauer 1971; Risser 1978).

Technological advances have also precipitated a series of environmental questions. Increased use of fertilizer has increased the possibility of additional nitrogen and phosphorus losses and contamination of surface and groundwater (Frere 1976; Rajagopal 1978). The rate of the natural aging process (eutrophication) of water bodies such as the Great Lakes has increased in recent times (Holt 1973; Beeton 1973; Frere 1976) and agricultural activities are believed to be partly responsible (IJC 1978). Furthermore since "Silent Spring" (Carson 1962), environmentalists have attacked the increased use of all pesticides despite their remarkable benefits to agricultural production in North America (Caro 1976). Some discontinued pesticides were extremely persistent; the damage done by organochlorine pesticides, for example, is well documented (Nicholson and Hill 1970). Present pesticides break down to non-toxic forms more rapidly but their ultimate effect on the ecosystem is still unknown. Toxic materials other than pesticides, eg. lead and PCB's, and their distribution and movement within the environment are another concern. Although not used agriculturally such materials are transported in agricultural drainage water (Coote et al 1978).

Stream sediment is another major environmental and agricultural concern. Sedimentation physically alters stream flow and disrupts the ecosystem (Guy and Ferguson 1970; Peters 1967) while the release of sediment-bound pollutants such as phosphorus and pesticides (Grissinger and McDowell 1970) degrade water quality. Agricultural land uses can affect the quantity and kinds of sediment-bound pollutants entering waterways (Stall 1972).

Recommendations for the reduction of pollution loadings to the lakes were included in the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Point sources which could be easily identified and monitered were the primary concern. Included in these were outfalls of urban sewage and industrial waste (Canada-U.S. Great Lakes Water Quality Agreement 1972). The agreement also requested that the International Joint Commission (IJC) investigate land drainage (including ground and surface runoff and sediments) to determine sources of the pollutant load not accounted for by the point source discharges. While there were many data on the effects of nutrients and pesticides on water quality, there were conflicting reports on the quantities of these materials coming from agriculture and other land uses (Garmen 1973; Barnett 1972; Wiebe 1973; Wadleigh 1971). The IJC created the Pollution from Land Use Activities Reference Group (PLUARG) to look into the problem (IJC 1978) and to:

1) determine and evaluate the location, causes, and extent of pollution from land use;
2) gain an understanding of the importance of various land use activities to pollution of the Great Lakes;
3) examine the effects of diffuse pollution loads on Great Lakes water quality; and
4) determine the most pratical and cost effective means of reducing diffuse pollution loads.

The IJC report on the PLUARG studies indicated a significant agricultural contribution to water quality degradation in the Great Lakes (IJC 1980). PLUARG did not attempt to assess the more comprehensive issue of agricultural impact on local water quality. However results such as the IJC nonpoint control levels I, II and III (Table 1), while intended primarily to reduce Great Lakes levels of phosphorus, can also serve as a basis for protecting local water quality.

Many studies have shown that management decisions made at the farm level (eg. choice of crops grown on a given soil and slope, use of rotations, types and methods of tillage operations, livestock and manure management systems and pest control programs) can affect pollution loads to surface and ground water (Stewart et al 1976). However land use was not found to be the dominant factor determining nonpoint source problems in the Great Lakes Basin (Sonzogni et al 1980). Land form characteristics (e.g. soil texture, soil type, surficial geology, slope, drainage density and soil chemistry) were more important. Overall the single most important characteristic was generally found to be soil texture, since it plays an important role in water movement within and over a landscape. Sections of the Great Lakes Basin which have sandy soils, such as the Upper Lake Michigan basin, have relatively good water quality while areas with clayey soils, for example the Lake Erie basin, tend to have poorer water quality despite similar land use.

Table 1. Phosphorus reduction alternatives for rural nonpoint sources

Nonpoint Controls	Rural
Level 1	sound management practices ie: proper nutrient application - minimized tillage for erosion control and optimum yields - mulching - avoidance of near-stream slopes
Level 2	level 1 plus: conservation tillage on fine-textured soils - contour strip cropping - use of cover crops - buffer strips - improved drainage practices
Level 3	level 2 at greater intensity of effort plus: engineered drainage improvements ie: tile outlet stabilization -stream bank stabilization

Adapted from IJC 1980.

A tentative grouping of southern Ontario soils into catagories determined on the basis of their potential for pollutant transfer to either surface or ground water was undertaken prior to the selection of the agricultural study areas of PLUARG. Five major groups were identified by criteria (eg. soil texture, parent material, drainage class and slope) which reflected their ability to transport pollutants to ground or surface waters or both (Coote and MacDonald 1974). The sandy soils of Norfolk County which exhibit rapid infiltration rates and are well drained illustrate a group considered to have a high potential for moving pollutants to ground water but low potential for affecting surface waters. On the other hand the fine textured soils found in much of Niagara and Haldimand have low infiltration rates implying a high degree of surface runoff. The potential for soluble and particulate pollutant transport to surface waters was therefore considered to be high, while potential for ground water contamination was low. Fig. 1 (see pocket) shows the other possible characteristic combinations and their potential for affecting water quality. Classification of Ontario soils under the system presents an overview of areas where runoff and erosion control practices might be especially important for protection of surface water quality. It also shows those areas where remedial measures will likely affect the volume and quality of percolating water. It assists in defining the nature of the problems to be considered in different areas of the basin. Individual farms may have soils in catagories different from those shown on the map and remedial measures cannot be determined without on-site information.

The complexity of individual farm characteristics of soil, climate, farm practices and watershed hydrology illustrates the difficulties of remedial measure selection and the reasons why broad legislative solutions for farm source pollution problems are at best simplistic, inefficient and difficult to apply. A more feasible approach is a comprehensive system involving

1) identification of regional and/or site specific problem areas,
2) on site assessment of the pollution hazard, and
3) preparation of recommendations outlining alternatives for improving the situation.

Guidance from informed land management specialists is required since not all practices are equally practical or feasible. The effects of pollution control measures on the economic viability of an operation must also be evaluated, as well as the effects on future management options.

The following sections will discuss the potential reduction of agricultural pollution which a farmer can achieve through alternate management techniques. Supporting information and data from research done in the Great Lakes Basin, and elsewhere, are provided.

2. RUNOFF, EROSION AND SEDIMENT

2.1 Introduction

Runoff, erosion and sediment transport present agriculturalists with two problems. Soil erosion by water (or wind) removes the most important portion of the surface soil reducing the agricultural production potential. Although the surface layer can be reconstituted the rate of soil formation is very slow and conventional thinking among soil scientists places it in the order of 1 to 5 tonnes per hectare per year. In cultivated fields soil loss due to erosion often exceeds these replacement rates. Runoff plots seeded to corn at the University of Guelph showed average soil losses of 1.8 t/ha/year on a 2% slope (Elora), 9.9 t/ha/year on a 6% slope (Elora), and 54 t/ha/year on 7-9% slope (Guelph). Management practices which maximized residue cover reduced soil loss (van Vliet and Wall 1979). Sediment, consisting of organic and inorganic matter, and associated plant nutrients represents an economic loss to the farmer (Burwell et al 1975) and becomes both a physical and chemical pollutant in waterways (Robinson 1971) because it:

- decreases channel capacity
- destroys aquatic habitats
- alters the composition of aquatic ecosystems
- creates turbidity
- decreases recreational value
- increases costs in treating water for human consumption and
- degrades water quality when it releases materials which can adhere to the sediment particles, (e.g. nutrients, pesticides, other toxic chemicals, pathogens and radioactive material from fallout) (Johnson and Moldenhauer 1970; Oschwald 1972).

Although farmland contributes a relatively small amount of sediment per unit area the cumulative sediment load from all agricultural lands in the Great Lakes Basin represents a significant portion of the fluvial input to the Great Lakes (Wall et al 1978). Generally runoff and sediment loads increase with increasing clay content (van Vliet et al 1978). The selectivity of erosion and runoff processes usually results in the preferential transport of the chemically active fine particles and organic matter while leaving the coarser material behind (Miller 1977). The fine clay and organic particles can concentrate nitrogen, phosphorus (Holt et al 1970), organic mercury compounds (Oschwald 1972), PCB's (Frank 1977) and heavy metals (Whitby et al 1978). PLUARG studies showed that between 40 and 80 percent of the total phosphorus tributary stream load was associated with sediment (IJC 1978), while 25-30 percent of the total nitrogen lost from agricultural land was attached to the sediment (Coote et al 1978).

Runoff also transports water soluble compounds which can contribute to eutrophication (nitrogen, phosphorus), result in toxicity to fish and other aquatic life (pesticides, ammonia), or render the water unfit for human consumption (PCB's, organic contaminants, pathogens).

The erosion potential of cropland is affected by the soil type, plant cover, topographic features, rainfall and snowmelt runoff. Water erosion begins with the shattering of soil granules and clods and the detachment of particles from the soil mass by raindrop impact. Splash action and overland flow transport some of the detached particles down slope, often moving them to areas where more concentrated run-off can carry them away. This insipient sheet erosion occurs uniformly over the slope and may go unnoticed until much of the productive top-soil is lost (Piest et al 1976). Even a loss of 22 tonnes/ha (10 tons/acre) in an erosive event would, on average, remove only 0.17 cm (0.06 inch) of soil distributed evenly over the surface. Such losses are visually undetectable. Severe rill and gulley erosion, while visually dramatic, is not widespread in Ontario and is usually only caused by high energy rainstorms or rapid spring snowmelt-runoff conditions.

U.S. researchers have considered the rate of rainfall erosion to be determined by four factors and their interrelationships. They are climate, soil, topography and plant cover (either living or dead) and are the basis of the Universal Soil Loss Equation (Smith and Wischmeier 1962). The equation states:

$$A = RKLSCP$$

where A = predicated average soil loss, expressed in ton/acre/yr, (1 ton/acre/year x 2.24 = tonnes/hectare/year),
R = a measure of the erosive potential of average annual rainfall at the site, expressed as a rainfall-erosion index,
K = soil erodability factor, expressed as tons of soil lost per acre per unit rainfall-erosion index on a standard plot (9% slope, 22.1 m long in continuous fallow, tilled up-down slope),
L = length of slope factor, expressed as the ratio of soil loss from a specified length of slope to that defined for K,
S = slope-gradient factor, expressed on the ratio of soil loss from a specified percent slope to that defined for K.
C = cropping management factor, expressed as the ratio of soil loss under a specified cropping management system to the loss under fallow conditions
P = erosion control practice factor, expressed as the ratio of soil loss with a specific conservation practice (e.g. contouring, strip-cropping) to that with up-down slope cultivation.

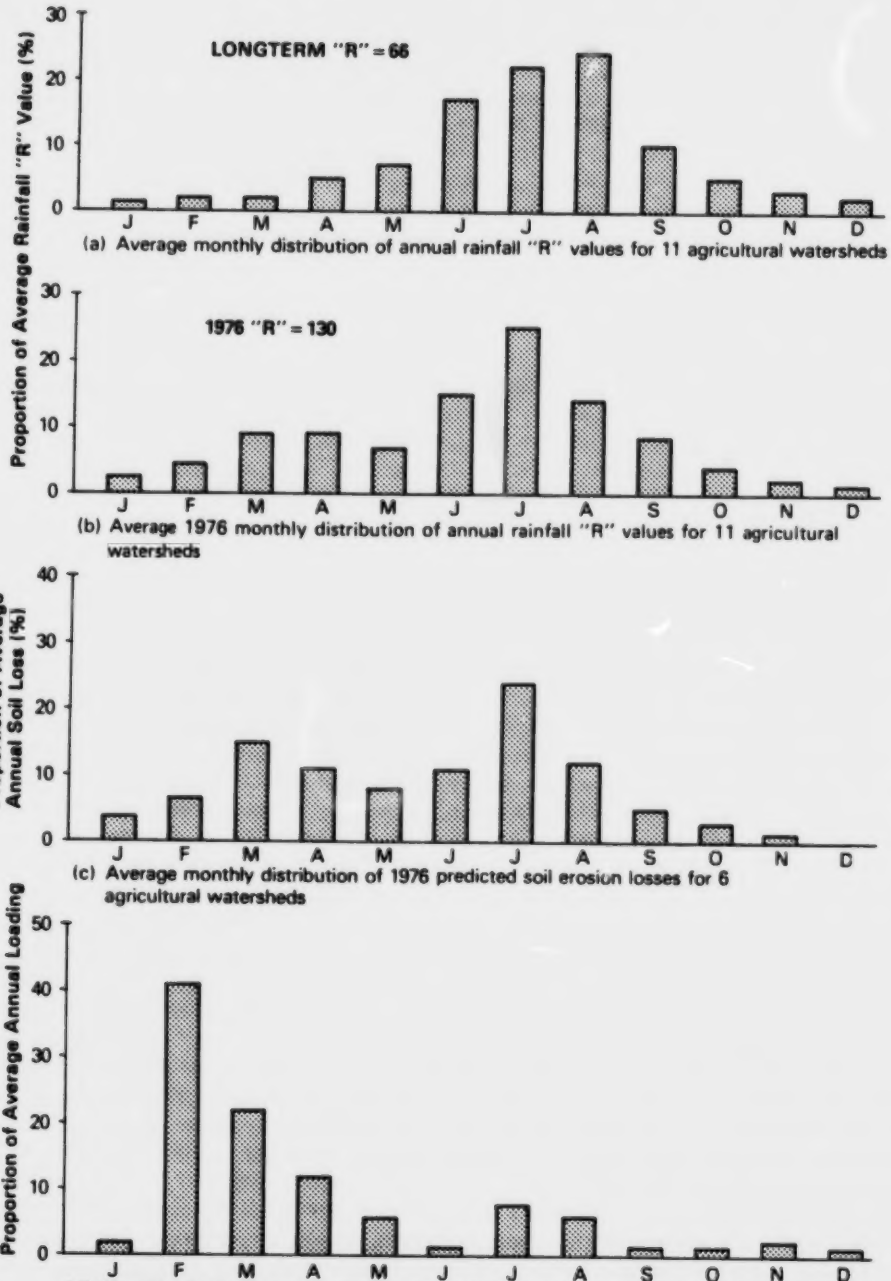
This equation estimates the soil loss at a given site once all the required information has been obtained. Practices which may reduce soil loss to an acceptable level are identified by the insertion of different C and/or P values based on land management practices (Wischmeier and Smith 1978). The U.S. Soil Conservation Service has used it successfully to develop individual farm plans for controlling soil erosion. However it was not designed to compute sediment delivery to streams, nor can it determine soil erosion during snowmelt and spring runoff, two significant factors when considering remedial measures for Ontario conditions. Its usefulness for water quality protection in Ontario is therefore limited.

Research has shown that the period from the beginning of snowmelt until the establishment of a vegetative cover is a critical time for erosion and runoff in the Great Lakes Basin (van Vliet et al 1978; Monke 1976) since the soil is generally saturated during snowmelt and little infiltration occurs. Further restriction of water infiltration at the beginning of the cropping season can result from the soil physical conditions produced by the traditional spring tillage practices for row crops (Burwell et al 1968). The lack of vegetation exposes the soil to the energy of falling rain and the increased runoff aids soil movement.

Rill erosion is becoming more common in Ontario during periods with little protective vegetation. This is especially noticeable in areas with extensive row crops and few conservation measures. With conventional seeding methods on clean-tilled fields, the soil has very little protection from the first tillage operation until a crop canopy forms. Although rainfall intensity and duration of storms varies both from year to year and in different periods within a year, major storms coinciding with this period of little or no vegetation can cause considerable erosion (Grier 1971). Normally, in the U.S. Great Lakes region, from 40 to 50 percent of the year's erosive rainfall occurs within two months of the average planting date of corn, soybeans and grain sorghum (Stewart et al 1975). Burwell et al (1975) also showed that much of the annual sediment and nutrient losses occured during the first two months after seeding and that snowmelt runoff accounted for much of the soluble nutrient losses.

In Ontario most of the erosive rainfall falls in the June, July and August period and predicted soil erosion losses tend to peak during this time (van Vliet et al 1978). However agricultural watershed sediment loadings data show that the peak sediment transport period in 1976 was in February, March and April (Figure 2). This indicates the importance, for water quality protection, of finding and controlling those areas which are hydrologically active during snowmelt and spring runoff. Only a small portion of a given agricultural landscape (usually <25 percent) actually contributes sediments to a stream. Contributing areas undergo wide fluctuations in size during the different seasons, however observations indicate that the January to April period has a high sediment delivery rate. This has been attributed to either frozen soil or high antecedant soil moisture content and lack of an effective ground cover to trap soil material during the transport phase of soil erosion. Sediment delivery is observed to be lower in the summer period, in spite of the high erosion potential, because most of the sediments are trapped in vegetated surface drainage pathways before reaching the main channel (van Vliet et al 1978).

Losses of water soluble materials are not as closely related to the season as they are to the time of a storm event relative to the application of the material to the land. A substantial rain shortly after fertilizer or pesticide applications can result in large portions of the applied material being carried off before it has become chemically



(a) Average monthly distribution of annual rainfall "R" values for 11 agricultural watersheds

(b) Average 1976 monthly distribution of annual rainfall "R" values for 11 agricultural watersheds

(c) Average monthly distribution of 1976 predicted soil erosion losses for 6 agricultural watersheds

(d) Monthly distribution of average sediment loadings for the 11 agricultural watersheds (Naquadat Method 1976 Data)

Reference van Vliet et al 1978

Figure 2. Relationships between the Rainfall 'R' Values, predicted soil erosion losses and average sediment loadings (monthly) for some Ontario agricultural watersheds.

bound to the soil or used by plants (Frank et al 1978). Pesticide concentrations in runoff have also been shown to vary by orders of magnitude during a single runoff event (Wauchope 1978). Pesticide runoff losses are further affected by the type of pesticide and the condition of the field (i.e. sod, fine tilled, minimum tilled or fallow). The impact of pesticide contaminated runoff on water quality may be mitigated however by such factors as dilution, sorption by untreated soil or stream sediments, or entrappment of the contaminated sediment before it reaches the stream. Also, land retention of sediment associated contaminants such as heavy metals and toxic organics (often deposited on the soil by atmospheric fallout) might be environmentally better than allowing them to wash into the water system. While farming practices cannot entirely protect the food chain from such contaminants, improved farming practices can reduce their transport to water courses through erosion, sediment and runoff controls.

2.2 Importance of Management Decisions

It is important both agronomically and environmentally to prevent sediment losses, since they represent a loss of investment to the farmer and they degrade water quality if they reach a water course. Soil loss and runoff can be reduced through the use of land management practices which protect the soil surface during the critical erosion and runoff periods, promote infiltration and dissipate raindrop energy before it hits the soil (Woolhiser 1976). Erosion and runoff control methods must be designed to do one or more of the following;

- dissipate raindrop impact energy;
- reduce quantity of runoff;
- reduce runoff velocity, and
- strengthen soil aggregation to reduce detachment and erosion.

In many cases erosion, runoff and sediment losses can be prevented or reduced by altering tillage methods, cropping sequences, crop residue management, seeding methods, soil treatment or timing of field operations. Improved infiltration may be a direct result of preserving and/or improving soil structure (Wischmeir and Mannering 1965; Carreker et al 1968) by protecting the soil with a vegetative cover or working it a minimum number of times, thus avoiding the destruction of the larger, more erosion resistant soil aggregates (Moldenhauer and Amemiya 1969; Moldenhauer et al 1971). The effect of altered tillage practices on soil loss potential is shown in Table 2.

Table 2. Potential soil loss reduction through conservation tillage (continuous grain corn) as determined from the Universal Soil Loss Equation.*

Tillage treatment	Reduction in potential soil loss as compared to fall plowed conventional tillage[1]
Zero-till	79%
Disc and plant	70%
Rotary strip till	53%
Chisel plow with points	30%

[1]Data represents an average for seven different agricultural regions in southern Ontario.

*adapted from van Vliet et al 1978.

From the standpoint of erosion control only, land preparation is best done in the spring. However the limited time available for spring seedbed preparation and planting may necessitate fall cultivation. The options are also limited on finer textured soils as research has indicated slightly lower yields in most years with systems other than conventional fall moldboard plowing followed by secondary spring tillage. Although the differences are not often statistically significant, researchers feel that conventional tillage results in consistantly higher yields than zero tillage on Ontario's medium and fine-textured soils (Vyn 1980). Table 3 shows the yield variations experienced with different tillage systems on a clay soil in Ontario. Yield reductions from some minimum till practices are not as noticeable on medium textured soils, as indicated by the data in Tables 4 and 5, and the small differences may be masked by other factors (e.g. weather, soil variations, management). The economic suitability of such systems for a specific operation will rely heavily on the individual level of management. The farmer should chose those systems which produce the optimum combination of surface roughness and residue cover, while minimizing yield loss, for those portions of his farm actively eroding.

Another management technique for controlling erosion and reducing runoff and soil loss is the selection of cropping system. Table 6 illustrates the difference in potential sheet erosion losses between various cropping practices. Choice of a cropping system must consider not only the effect on soil and water loss but also the effect on yield. Table 7 shows how variations in slope, crop, use of rotations and direction of work all affect soil loss, runoff and yield. The data show that it is possible to protect water quality without sacrificing yield.

Remedial measures to help reduce runoff and sediment pollution will be most needed in areas with a high percentage of row crops and with clay soils. Simulation techniques have shown that reducing soil erosion on sediment source areas can result in potential sediment reductions of up to 75 percent (van Vliet et al 1978).

Improved cropping practices alone will not be enough to protect water quality in problem areas. Special support measures such as diversions, controlled surface runoff inlets and outlets and grassed waterways will be required. Depending on the site (slope, soil type, climate and cropping program), more than one practice may be necessary. Some practices may need modification to suit an individual farming situation while others may be totally unsuited. Since only about 15 percent of a total watershed area is actively contributing eroded material to the streams and influencing water quality (van Vliet et al 1978), the total land area will not require the same degree of erosion and runoff protection. A cover-crop, spring plowing with minimum tillage or no-till can be used in specific areas with high

Table 3. Effect of tillage on grain corn yield on clay soil in southern Ontario.*

Tillage treatment	Grain yield (dry matter) (t/ha)			
	1977	1978	1979	1977-79
Fall moldboard plow plus spring secondary tillage of:				
- disc plus cultipack once	5.8	4.0	4.1	4.6
- disc plus cultipack twice	5.7	4.1	4.0	4.6
- disc plus cultipack four times	5.8	4.2	4.0	4.6
- disc once, cultivate plus cultipack three times	5.9	3.6	3.8	4.4
- disc once plus reciprocating harrow	5.6	4.0	4.2	4.6
Fall chisel plow plus secondary tillage of:				
- disc plus cultipack twice	5.6	3.4	3.8	4.3
- disc plus cultipack four times	5.5	4.0	3.1	4.2
Spring plow, disc plus cultipack four times	5.5	4.8	3.0	4.4
Disc plus cultipack four times in spring	5.2	4.1	3.4	4.2
Zero tillage[1]	4.6	4.2	4.0	4.3
Standard error	0.62	0.56	0.41	

1 Due to severe crusting on all the tilled treatments in 1978 and 1979, the zero tillage treatment had approximately 20% higher plant populations in both years.

* Vyn et al 1980.

Table 4. Grain corn yield comparisons for different tillage systems on four soil textures in southern Ontario in 1976-77.*

Tillage	Soil type			
	Sandy loam	Loam	Silt loam	Clay[1]
	% of zero tillage			
Fall moldboard plow plus spring secondary	110	109	118	127
Spring moldboard plow plus secondary tillage	102	106	113	120
Fall chisel plow plus spring secondary tillage	108	106	109	121
Offset disc in spring	109	108	105	115

[1] 1977 only.

* Vyn et al 1979.

Table 5. Average corn grain yields in relation to tillage practices on three soil types in southern Ontario (1975-79)*

Tillage treatment	Soil texture		
	Sandy loam	Loam	Silt loam
	----Grain yield as % of zero tillage--- (number of test years)		
Fall moldboard plow only	115 (4)	109 (3)	111 (4)
Fall plow; spring disc, harrow	117 (4)	111 (4)	119 (4)
Spring moldboard plow	111 (4)	108 (5)	104 (4)
Spring plow, disc, harrow	111 (4)	106 (5)	115 (4)
Fall chisel plow only	107 (3)	96 (3)	104 (4)
Fall chisel; spring disc, harrow	109 (3)	111 (4)	115 (4)
Off-set disc in spring, harrow	111 (4)	107 (5)	109 (4)
Rototill in spring	110 (2)	112 (2)	108 (2)

* Vyn 1980.

Table 6. Magnitude of potential sheet erosion losses from cropland in southern Ontario as determined by the U.S.L.E.*

CROP	SHEET EROSION LOSSES BY CROP	
	Mean (t/ha/yr)	Range[1] (t/ha/yr)
Horticultural crops (potatoes, tomatoes, etc.)	9.1	6.6-12.2
Beans (soy and white)	7.6	5.5-9.8
Continuous corn	9.1	2.9-11.7
Corn in rotation[2]	3.7	0.9-6.9
Tobacco	3.5	2.1-4.9
Small grains	3.4	1.5-6.9
Meadow in rotation[2]	2.6	0.9-5.0
Permanent pasture	0.4	0.1-0.8
Woodlands	0.2	0.05-0.4

1 Range of values reflects soil, topographic and rainfall variations between watersheds.

2 Rotation values represent the average values achieved when crop grown in common Ontario rotations.

* van Vliet et al 1978.

Table 7. Average annual crop yields, total water loss and total soil loss under various treatments on Rideau clay for 12 years[1] at Ottawa.*

Crop and treatment	Total soil loss tonnes/ha	Total water loss tonnes/ha	Average annual yield tonnes/ha
Corn			
Rotation[2]-manured-grown on level land	0	0	28.3
Rotation-manured-grown on contour on 10% slope	93.6	1075.2	22.4
Rotation-manured-grown up and down 10% slope	125.2	1244.3	17.8
Continuous-manured-grown up and down 10% slope	440.6	4965.0	10.3
Continuous-no manure-grown up and down 10% slope	591.8	6000.3	7.1
Oats			
Rotation[2]-manured-grown on level land	0	0	2.1
Rotation-manured-grown on contour on 10% slope	46.4	808.9	1.4
Rotation-manured-grown up and down 10% slope	53.8**	937.0**	1.4
Continuous-manured-grown up and down 10% slope	33.6**	571.2**	0.8
Alfalfa			
Rotation[2]-manured-grown on level	0	0	6.8
Rotation-manured-grown on contour	0.2	110.4	6.2
Rotation-manured-grown up and down 10% slope	1.3	160.4	8.2
Continuous-manured-grown up and down 10% slope	0.5	138.0	6.9
Other			
Timothy-continuous-manured-grown up and down 10% slope	1.6	303.5	4.0
Summer fallow-manured-grown up and down 10% slope	411.7	3992.1	-
Summer fallow-no manure-grown up and down 10% slope	510.9	4354.6	-

1 1945 - 1956 inclusive

2 Four year rotation of corn-oats-alfalfa-alfalfa.

** Estimated; the runoff water flowed under the collection troughs.

* Ripley et al 1961.

erosion potential, while more conventional tillage is used elsewhere on the farm. This would help protect water quality without drastically reducing overall farm yields. Management of other areas would require balancing the benefits (eg. reduced soil loss, energy consumption and time) against the disadvantages (eg. possible yield reductions and/or increased input costs, lack of market). It is possible, however, that management alterations could result in an unequal financial burden for individual farmers (Meta Systems Inc. 1979; Miller and Gill 1976). In areas where the changes would require additional equipment, labour and/or market outlets (e.g. when hay cropping is added to a previous corn-soybean system), it may be necessary to provide incentives for farmers to institute the changes.

Improvements in water quality will be achieved most efficiently if time and effort are first applied to those areas actively contributing to the water courses. The following sections describe a variety of practices with the advantages and disadvantages of each.

2.3 Alternative Management Practices For Reducing Agricultural Soil Erosion, Runoff And Sediment Loss

2.3.1 No-till (zero-tillage) planting

Zero-tillage, possibly the most effective means of reducing soil erosion, involves no seedbed preparation other than opening a narrow slot with a fluted coulter for seeding. Residues remain on the soil surface throughout the year, providing maximum soil protection from raindrop impact and runoff water. No-till planting can be done in chemically killed meadow or winter cover crop, small grain stubble, chopped corn stalks or other crop residue. The vegetative mulch:

- protects the soil surface from raindrop impact,
- reduces detachment of soil particles,
- reduces surface sealing and crusting,
- slows water movement,
- traps sediment particles in the runoff, and
- allows more time for infiltration during the critical two month period between seeding and crop establishment (Meyer et al 1970).

The residue can reduce erosion, runoff and sediment loss both during the growing season and after harvest. Reduction of runoff and sediment loss in the critical January-April period is uncertain, however as the soil is usually frozen or saturated at this time and increased infiltration is unlikely. Maintenance of surface residues by zero tillage has, however, been shown to decrease water runoff and soil loss considerably under Ontario conditions (Table 8) (Vyn et al 1979).

Table 8. Effect of tillage and residue on mean annual water and soil loss with continuous corn on a Guelph loam with 7% slope, 1971-1976.+*

Treatment	Water loss		Soil loss	
	Summer	Winter	Summer	Winter
	cm		t/ha	
Corn stover left as a residue				
Fall plowed	2.5	8.2	23.7	7.0
Zero tillage	1.1	6.0	3.1	0.3
Corn stover removed				
Fall plowed	2.5	8.3	40.8	8.9
Zero tillage	3.7	9.6	37.2	6.7

+ Mean annual precipitation = 84 cm.

* Vyn et al 1979.

The crop sequence is important when considering no-till planting since runoff and sediment losses greater than those from conventional systems have occured when (i) poor residue cover and reduced surface roughness coincide, as after silage corn, or (ii) compaction and reduced infiltration have resulted on fine textured, weakly structured soils (Whitaker et al 1973). Prevention of such losses is especially important considering the high quantities of pesticides and fertilizer usually associated with no-till and the possibility of contamination of the runoff water.

Elimination of fall cultivation in cooler regions has been found to slow soil warming and reduce evaporation in spring, thereby delaying planting and slowing germination with resulting poor stands and reduced yields (Moldenhauer and Amemiua 1969). Ontario research has been unable to verify this effect although yields are consistently lower on most soils. With corn the potential for no-tillage systems in Ontario would therefore appear to be limited to sands and gravelly loams, and possibly following a grass-legume sod (Table 9).

No-till planting may increase pest populations. In southern Ontario annual fall plowing helps reduce the number of soil insects which overwinter underground (Vyn et al 1979). The presence of abundant residue cover during the rainy humid late spring period has also resulted in damage to field crop seedlings by garden slugs.

Growth and yields of some crops, especially cereals, have frequently been reduced where residues remained on or near the surface, indicating a possible phyto-toxicity (Elliot et al 1978; Parker and Larson 1962; McCalla and Norstadt 1974). Residue related yield reductions were not detected however, when corn was grown under no-till management on warm, well-drained soils (Bennett et al 1976; Van Doren Jr. et al 1976).

A further disadvantage of no-till is the limitation of placement options for pesticides and fertilizers (Vyn et al 1979) which often results in higher pesticide and nitrogen requirements to maintain yields (Stewart et al 1975). As well, the increased organic carbon levels near the soil surface may further limit nitrogen availability for use by the crop (Brady 1974). Thomas and Blevins (1977) observed that zero tillage resulted in increased and deeper nitrate leaching and less nitrogen mineralization, resulting in lower nitrate concentrations in the upper soil layer. Ontario crop scientists have suggested that ten to twenty percent more N may be required for zero tillage that conventional tillage to achieve optimum yields (Vyn et al 1979).

Table 9. Percent yield increase of conventional tillage over zero tillage for corn grown on various soil types and following different crops (average of Ontario tests).+*

Soil type	Number of tests	% increase
Sandy, gravelly loams	16	2
Loam, silt-loam	27	18
Clay, clay-loam	12	19
Previous crop		
Grass-legume sod	6	4
Grain corn	49	15

+ Conventional tillage consisted of fall moldboard plowing plus discing and harrowing in the spring.

* Vyn et al 1979.

2.3.2 Minimum tillage and residue management

Minimum tillage refers to conservation tillage-systems which do not invert the soil, thereby retaining previous crop residues on the surface and requiring fewer field operations than conventional moldboard-plow based tillage. The whole field may be cultivated or just a narrow strip where the crop is planted. Table 10 illustrates the degree of residue incorporation associated with individual tillage practices. Examples of minimum till systems include:

1) disc and plant systems which use a no-till planter in disced residue. The soil surface is not worked in the fall and retains a rough surface after planting. Incorporation of some residue results in slightly less protective cover than with zero-tillage, so that it is slightly less effective for erosion control;

2) rotary strip tillage which prepares a seed row 20 cm wide by 10 cm deep, leaving the inter-row space undisturbed. It provides a finer seedbed than the previous treatments and mixes about 1/3 of the residue with the surface soil (Oschwald 1973). The field has greater erosion potential than with previous treatments however, since a smaller percentage of the total field surface is protected by mulch; and

3) chisel plowing just prior to corn planting (studied using points to a depth of 20 cm). It is the least effective of conservation tillage methods since it disturbs more soil and incorporates more crop residues than any of the three previous systems (Table 2).

Minimum-till systems provide a variety of options resulting in wider adaptability than no-till. Their acceptability also increases as the texture of the soil becomes coarser. In Ontario they appear better suited for small grains and corn than for soybeans, white beans or vegetables.

Reductions in erosion, runoff and sediment loss will depend on the physical condition of the soil surface (Burwell et al 1966), amount of residue on the surface and the combined effect on infiltration and retention of water and sediment in the field. Residue micro-barriers also decrease runoff velocity allowing entrappment of sediment and increased infiltration time (Siemens and Oschwald 1978). Data in Table 11 show the increased degree of infiltration observed when mulch rates ranged from zero to almost nine tonnes per hectare. Runoff and soil losses were reduced to zero.

Table 10. Effect of tillage on surface residues*

Condition or type of equipment	Estimated surface residue remaining after a given operation (Percent)
1) After decomposition loss over winter	70-80
2) Chisel Plow (shanks spaced 30.5-38 cm (12-15 in.))	
a. straight shovel points	60-80
b. twisted shovel points	40-60
3) Disc (tandem or offset)	
a. less than 58.4 cm (23 in.) diameter blades	60-80
b. 58.4-71 cm (23-28 in.) diameter blades	40-60
c. more than 71 cm (28 in.) diameter blades	20-40
4) No-till planter (fluted coulter)	95-100
5) Strip or till planter	85-90

* Adapted from: Ohio State University. Ohio Erosion Control and Sediment Pollution Abatement Guide, 1979.

Table 11. Effect of rates of applied wheat straw mulch on runoff, infiltration and soil loss from Wea silt loam (Indiana) with 5% slope.

Mulch rate (t/ha)	Surface cover %	Water applied[1] (cm)	Runoff (cm)	Infiltration (cm)	Soil loss (t/ha)
0	0	15.9	7.2	8.7	27.8
0.5	40	15.9	7.2	9.5	7.2
1.12	60	15.9	4.0	11.9	3.2
2.24	87	15.9	0.8	15.1	0.7
4.48	98	15.9	0.2	15.6	0.0
8.96	100	15.9	0.0	15.9	0.0

[1] Water applied at constant intensity of 15.9 cm per hour.

* Adapted from: Mannering and Meyer 1963.

Surface residue levels are affected by tillage systems and the subsequent effects on soil and water loss apply over a range of slopes as illustrated in Table 12. Statistical analysis of these data did not indicate a significant interaction between slopes and tillage systems, however runoff did vary inversely with the amount of soil disturbance. Changes in slope had little effect on soil loss once the soils were stabilized, and the ridge system lost substanially less soil than either of the other systems for all three slopes. Runoff values for the ridge system were similar on all three slopes indicating that mulches on untilled soil reduce soil loss but do not increase infiltration as they do on tilled soil (Moldenhauer et al 1971).

The ridge plant system is uncommon in Ontario but has been used successfully in Quebec on clay soils without yield reductions (Engineering and Statistical Res. Inst. 1979). It may prove suitable for Ontario conditions as a method of soil conservation. Special equipment is used to accentuate the ridge where the seed is planted. This system promotes high soil temperatures for germination and early growth while leaving residues undisturbed. Erosion and runoff are controlled by these residues with less effect on yields than other minimum tillage methods (Moldenhauer et al 1971).

Another innovative form of minimum tillage with potential for Ontario is strip tillage (till-plant) where the seeding zone is prepared with rotary hoe sections, sweeps, shovels or a rotary tiller in front of the planter unit. Plant residue is deflected in between the rows. Herbicides can be used to control weeds in the seeded rows, while interrow weeds are controlled with disc hillers and one wide sweep preceded by a sharp coulter (Moldenhauer and Amemiga 1969). This method however, generally requires capital outlay for new equipment or modifications to existing machinery.

Minimum tillage would likely provide adequate protection against soil erosion in Ontario in cases were erosion and runoff are not excessive. Reduced tillage in row crops has been successful in providing better erosion control than that obtained by changing to small grains, or by contour strip cropping (Moldenhauer et al 1971). A combination of practices would be practical for many farmers, allowing them to reduce soil loss without large yield reductions. For example, in southwestern Ontario a farmer could reduce excessive runoff and sediment loss from his farm by using no-till or minimum till on the coarser textured soils if a severe erosion hazard existed. Minimum or conventional tillage could be used on the remainder of the farm. Where fall plowing is considered essential on heavy clay soils some of the benefits of minimum till might be achieved by spreading a surface mulch of straw, bedding litter or manure. If manure is used adequate runoff controls are necessary to prevent water pollution from nutrient runoff (Giddens and Barnett 1980). The topography of the land, probable storm events, proximity to a stream and the presence or absence of a vegetated "buffer strip" will determine the practicality of a manure mulch on fall plowed land. Fall mulch application without incorporation

Table 12. Runoff and soil loss as affected by slope and tillage system with simulated rainfall.*

Tillage system	3.4% Slope		6.9% Slope		9.0% Slope	
	Total runoff (cm)	Soil loss (t/ha)	Total runoff (cm)	Soil loss (t/ha)	Total runoff (cm)	Soil loss (t/ha)
Conventional (plow, disc & harrow)	14.7	45.0	-	-	13.2	82.2
Till-plant	12.2	25.3	15.2	62.7	12.2	56.0
Ridge plant	16.3	15.2	15.5	17.9	15.2	13.2

*Adapated from: Moldenhauer et al., 1971.

can aid water quality providing that the field is not located in a flood plain and precipitation is not generally excessive (Young and Mutchler 1976; Young and Holt 1977; Klausner et al 1976).

Advantages of minimum tillage over no-till include it's applicability on a wider variety of soils and the greater choice in placement of pesticides and fertilizers. Although minimum tillage allows these additions to be made within the soil, good management of pesticide and fertilizer applications is required to maintain yields since reduced soil disturbance will limit their distribution in the soil. Use of a till-plant or ridge system will help prevent yield reductions during a wet spring when excessive surface mulches can delay planting. Capital costs can be minimized by making equipment modifications locally rather than purchasing new equipment. Disadvantages include the deleterious effects of excessive surface mulch, increased pesticide use and reduced nutrient mobility within the soil. Fertilizer and pesticide placement options are limited and although adaptable to a wider variety of soils, minimum tillage does provide less effective erosion control than zero tillage (Stewart et al 1975).

2.3.3 Crop rotations

Crop rotations were once an accepted practice in Ontario and the beneficial effects on yields are well documented. Data from Guelph and Ottawa (Table 13) show that not only yields but also soil and water losses were influenced by crop rotations.

The expanded growing area for crops such as corn and beans, (due to the introduction of shorter season varieties and improved herbicides), has resulted in large areas under monoculture (continuous) row-crops. It now appears that this change is having a significant impact on water quality because of the increased soil and runoff losses associated with continuous row-cropping.

Good crop rotation practices will reduce soil loss to less than 50 percent of that observed with continuous cropping (Laflen and Moldenhauer 1971). The preferred crop rotations have at least one year in sod. Soil loss from a good quality grass and legume meadow is negligible (van Vliet et al 1978; Laflen and Moldenhauer 1971), and the residual effect from plowing under the sod improves infiltration and leaves the soil less susceptible to erosion during the remainder of the rotation (Moldenhauer et al 1967; Mannering et al 1964; Webber 1964). Table 14 illustrates the expected effect of rotations on soil loss in Ontario.

Data collected on the Great Plains over many years have been used to predict possible soil loss reductions for rotations used under varying conditions. The predicted advantages of a sod rotation over a corn-corn-soybean rotation ranged from 11.2 to 51.6 tonnes of soil saved per hectare per year (Table 15).

Table 13. Effect of crop rotation on mean annual soil and water losses and crop yield; 7 to 10% slopes at two locations in eastern Canada.*

Treatment	Mean annual soil and water losses[1]				
	Guelph (Guelph loam soil), 1953-1963[2]		Ottawa (Rideau clay soil), 1945-1957[3]		
	Water cm	Soil t/ha	Water cm	Soil t/ha	Corn silage yield t/ha
Corn-oats-hay-hay rotation	0.7	1.9	1.0	10.6	20.0
Continuous corn	3.1	19.0	4.1	36.2	13.0

[1] Losses averaged over experimental period.

[2] L.R. Webber 1964.

[3] P.O. Ripley et al 1961.

* Vyn et al 1979.

Table 14. Estimated reduction in soil loss with different cropping practices (compared to continuous corn or beans).*

Cropping Practice	% reduction[1]
Mixed grain or winter wheat	40
Rotation of: 1 year corn, 1 year grain, 2 years hay-pasture or 3 years corn, 3 years hay-pasture	60
Rotation of: 2 years corn, 4 years hay-pasture	70
Hay-pasture	87
Permanent pasture	93

[1] Values estimated from the Universal Soil Loss Equation by substitution of approximate "C" value.

* Moore et al 1979.

Table 15. Soil losses expected for several cropping systems, slopes, and slope lengths.*

Cropping System	Percent Slope 3		6		9	
	Slope Length (m) 120	75	90	39	60	37.5
	t/ha[1]					
Fallow	78.4	62.7	150	98.6	212.8	168
Corn-corn-soybeans (with no surface residue)	26.9	11.2	53.8	17.9	76.2	35.8
Corn-corn-soybeans (with 66% soil coverage by surface residue)						
2.24-3.4t/ha crop residue	22.4	9.0	40.3	13.4	60.5	29.1
3.4-4.5t/ha crop residue	17.9	9.0	35.8	11.2	51.5	24.6
4.5-6.7t/ha crop residue	15.7	6.7	29.1	9.0	42.6	20.2
Corn-oats-meadow (residues ploughed under for corn)	4.5	2.2	9.0	4.5	13.4	6.7
Corn-corn-oats-meadow (residues ploughed under for corn)	9.0	4.5	17.9	6.7	24.6	11.2
Continuous grass-alfalfa sod	0.2	0.1	0.7	0.2	0.9	0.4

[1] USDA, SCS, Work Unit Technical Guides, Section III-B, developed from data for the Great Plains.

* Laflen and Moldenhauer 1971.

Table 16. Effect of crop rotation on aggregate stability and crop yield on Haldimand clay soil (1953-1964).*

Crop	Water - stable aggregation %	Yield of grain corn (t/ha)
Continuous		
- corn	22	4.6
- Blue grass	85	
Rotation		
- 1st year - corn	52	5.2
- 2nd year - oats	56	
- 3rd year - hay	61	
- 4th year - hay	74	

* Webber 1964.

The beneficial effect of a sod-based rotation has been attributed to the extensive root-systems of clover, grasses and alfalfa which improve soil struture by increasing the percent of water stable aggregates, an important factor in maintaining the macro and micro soil pores. Table 16 shows how the aggregate stability increases with increasing length of time in sod. Increased stability decreases dispersion while the protective canopy reduces the shattering effect of raindrop impact and slows the surface runoff velocity. This allows more infiltration, less erosion and increased entrappment of soil particles.

Good hay stands require adequate fertilization so there is some potential for soluble fertilizer components to be carried away in surface runoff before being taken up by the plants. There is also the possibility of increased nutrient movement from the leaching of the extra plant material undergoing alternating freeze-thaw cycles (Timmons et al 1970; Robbins and Carter 1980).

The compatibility of crop rotations with an existing operation must be considered. A farmer operating a cash-crop system may not have a ready market for the hay and small grain crops required in the most suitable crop rotations. Proper equipment and/or labour may also be a problem. From the farm cash-flow viewpoint, it is still unknown if crop rotations are economically feasible strictly for the maintenance of soil structure and erosion control. However there are areas in southwestern Ontario where continuous corn has resulted in decreased yields and farmers have returned to crop rotations in an attempt to eliminate the problem (Anonymous 1980a). Crop rotations would become a more attractive alternative if improved market availability for forage and small grains were to reduce the income difference between continuous corn and rotation systems.

A further disadvantage of crop rotations is that wireworms, cutworms, white grubs and army worms can be more prevalent in the first year of corn after sod (Stewart et al 1975). On the other hand some pest problems associated with continuous cropping systems, e.g. corn rootworm, are reduced by altering the insect habitat conditions (Pitblado 1976).

The beneficial effects of rotations are less certain when they do not include a sod crop. A rotation without sod may still provide improved aggregate stability and increased infiltration rates. It may also reduce the amount of herbicide required and assist in controlling certain pests. Non-sod rotations which seed a fall crop immediately after a row crop protect the soil surface for most of the year. However non-sod rotations must be carefully managed if they are to be effective. Corn following soybeans has a higher erosion potential than corn after corn, while a soybeans-soybeans system has an even higher erosion potential (Stewart et al 1975). Erosion could be reduced with a corn-soybeans-oats rotation. Whether or not a small grain crop is economically feasible, minimum tillage should be used to help retain crop residues on the surface. The main objective is to maximize soil protection by residues from previous crops whenever possible.

2.3.4 Improved soil tilth and fertility

Soil tilth refers to the physical condition of the soil. It is related to the ease of tillage and fitness of seedbeds for seedling emergence and root penetration. Soil susceptibility to erosion and runoff losses is related to the above factors as they affect soil infiltration capacity and ability to resist detachment and transport by splash and runoff.

Good soil structure and tilth can be maintained and improved by proper land management, but it can also be destroyed through poor management. Soil structure can be preserved and enhanced by practices which increase the degree of aggregate stability. This can be accomplished through the use of crop rotations involving legumes, and ammendments of organic matter by incorporation of residues, manures and green manure crops. The water stability of soil aggregates generally increases with the increasing organic matter content which acts as a strong bonding agent. The organic matter provides strength to soil aggregates which reduces puddling and surface crusting by minimizing their tendancy to fracture or slake when wet (Vyn et al 1979; Wischmeier and Mannering 1965; Carreker et al 1968). Degradation of soil structure by excessive tillage or tillage when the soil is wet can lead to accelerated erosion. Poor structure also makes soils more susceptible to compaction from traffic over wet soils (e.g. the movement of heavy manure spreaders over the fields in the spring). Formation of a compacted soil layer reduces infiltration, increases runoff, restricts root development and slows crop emergence and growth. The resulting poor stands provide inadequate protection from rainfall and as a consequence erosion increases. Lower yields may also result though this has yet to be demonstrated in Ontario. Wet fine textured soils are particulary susceptible to soil structure damage from machinery traffic (Vyn et al 1979). Preventative measures include fall plowing of clay soils when dry, use of crop rotations, returning crop residues to the soil to maintain organic matter levels, yearly variations in implement working depth and the use of manure and green manure crops. Although compaction is difficult to predict, evidence suggests an increased degree of compaction on soils under continuous row crop production.

The strength of the soil can be decreased by plowing too deeply since this incorporates subsoil which is low in organic matter and plant nutrients. Continued subsoil incorporation can decrease the pore spaces and restrict air and water movement. Ultimately crop yields may be reduced (Table 17). Plow depth is best maintained at about 10 cm, with occasional deeper plowing (15-20 cm) in some soils to prevent formation of a plow pan (Vyn et al 1979). A chisel plow can be used where the topsoil is too shallow for deep moldboard plowing.

Table 17. Effect of plowing on yield of corn grown on Brookston clay.*

Depth of fall moldboard plowing (cm)	Average grain yield (1968-1974) (t/ha at 15.5% moisture)
10	6.7 a[1]
20	6.6 ab
30	6.4 b

[1] Means with common letter not significantly different from each other using Duncan's multiple range test; $p \leq 0.05$.

* Bolton et al 1976.

Superior crop management which maintains soil tilth provides erosion control through rapid crop establishment and increased crop growth and canopy cover. Good soil fertility levels which allow the use of narrower row widths and increased plant populations without yield reductions can enhance these benefits. Narrower rows and higher plant densities establish continuous cover earlier and also smother weeds. Increased interception of rainfall by the plant canopy reduces the erosion potential. Soybean yield data have indicated a 13 and a 5 percent advantage of 18 cm over 53 cm and 36 cm rows respectively (D.J. Hume, Univ. of Guelph, Guelph, Ontario, unpublished data). Corn likewise has shown yield increases when row widths are reduced from 102 cm to 75 cm on well drained "early" soils, and to 95 cm on "later" soils (T.B. Daynard, Univ. of Guelph, Guelph, Ontario, unpublished data). Increased crop growth also removes more soil water, allowing more infiltration during storms, and produces more residues for return to the soil. Soil tests should be used to determine fertilizer needs and ensure correct applications. Excessive amounts can increase nutrient losses by leaching and runoff and can result in water quality problems for both surface and ground water supplies. Insufficient quantities of plant available nutrients restrict yield and plant growth resulting in less effective soil cover and reduced amounts of organic residue.

Maintenance of good soil tilth and fertility should be an integral part of all farm plans and generally does not require large investments in new equipment or soil conservation structures. The resulting improved soil structure will eventually provide better yields and lower erosion potentials during the growing season. However the degree of control over soil losses during the critical snowmelt and early spring periods has not been quantified.

2.3.5 Winter cover crops

Winter cover crops are often beneficial in areas where snowmelt and spring rainfall cause severe erosion, runoff and soil loss. A well established crop can slow snowmelt runoff, reduce the scouring action on frozen soils, protect the soil from impact of spring rains and trap sediment particles. It is useful where residue from previous crops provides insufficient protection from rain drop impact and runoff, or as an integral part of a crop rotation schedule. It has also been suggested that cover crops can reduce nitrogen leaching through uptake, especially on soils with a high residual nitrogen level (Stewart et al 1975; Neilsen et al 1978) but this has not been verified.

The cover crop, usually small grain, is planted in the fall for overwinter protection. Where late harvesting or weather conditions are likely to make fall seeding difficult seed can be applied from aircraft before the previous crop is harvested, providing soil rutting and mixing from harvest operations will not be severe. The

cover crop can then be incorporated into a spring cropping program by working it into the soil or chemically killing it. The residue provides a mulch for minimum till or no-till corn during the first season. Alternatively, if winter cereals are planted they can be harvested for grain the following year.

Red clover interseeded in oats in a corn-small grains rotation is another winter cover crop possibility. The red clover plus oat stubble provides protection after the oats are harvested and corn can be planted the following spring. Although legume seed can be expensive, the residual soil nitrogen can improve yields of succeeding crops.

The main disadvantages of a winter cover crop occur when it is used as the residue source for no-till or minimum till corn (e.g. extra cost without cash return and problems with fertilizer and pesticide placement). Contact herbicides are also less effective where high levels of residue prevent direct contact with weed seedlings.

2.3.6 Timing of seasonal operations

Erosion research has indicated that fall plowing will increase soil loss from 10-24 percent compared with spring plowing (van Vliet et al 1978; Stewart et al 1975). Fall plowing is necessary, however, in areas where early spring wetness delays field operations and the number of good working days is limited (Table 18). A delay in planting beyond the optimum planting dates for spring grains and corn can result in sizeable yield reductions, as indicated in Table 19 (Van Die et al 1979).

A comparison of these two tables shows that, on average, there are only 6.8 planting days available in southwestern Ontario which could result in maximum corn yields on loam and clay soils in 2 out of 3 years. Elimination of fall plowing, which promotes seeding at the optimum time, is therefore unlikely to be acceptable on economic grounds. Fall plowing is also a recommended practice on nearly level soils of moderatly fine to fine texture and for control of weeds and insects when removing a field from sod (Stewart et al 1975). Much of the sediment from fall plowed fields can be kept out of streams and ditches if the runoff is filtered through a buffer strip, and fields along streams are planted to hay or a winter cover crop.

Timeliness is important not only for good yields, but for erosion and runoff control as well. Late seeded winter wheat will be ineffectual for erosion and runoff control if it is not properly established during the fall. Delayed spring corn planting results in exposed soil surfaces during the periods of greatest rainfall intensity (van Vliet et al 1978). Furthermore, poorly timed tillage, harvesting and

Table 18. Expected number of good field workdays per week in the spring on well-drained soils at two probability levels.*

Week of	Loam and clay soils		Sandy soils	
	2 out of 3 years	4 out of 5 years	2 out of 3 years	4 out of 5 years
	Southwestern Ontario (Harrow)			
Apr 12-18	-	-	3.3	2.1
Apr 19-25	0.7	-	4.1	3.0
Apr 26-May 2	2.5	1.0	4.8	3.6
May 3-9	4.3	2.8	5.8	4.9
May 10-16	3.6	2.0	5.2	4.1
May 17-23	3.5	2.0	5.6	4.7
May 24-30	4.6	3.1	6.1	5.4
May 31-June 6	4.7	3.5	5.9	5.1
June 7-13	3.8	2.6	5.5	4.8
June 14-20	3.7	2.4	5.6	5.0
Total	31.4	19.4	51.9	42.7

Week of	Loam and clay soils		Sandy soils	
	2 out of 3 years	4 out of 5 years	2 out of 3 years	4 out of 5 years
	Central Ontario (Average of Guelph, Lindsay and Vineland)			
Apr 12-18	-	-	1.9	0.8
Apr 19-25	-	-	3.5	2.4
Apr 26-May 2	2.0	0.6	4.6	3.5
May 3-9	3.1	1.6	5.1	4.0
May 10-16	2.5	0.9	4.6	3.4
May 17-23	2.1	0.7	4.8	3.9
May 24-30	3.4	1.8	5.7	4.9
May 31-June 6	4.5	3.1	6.1	5.3
June 7-13	4.6	3.4	5.9	5.3
June 14-20	4.3	3.0	5.9	5.1
Total	26.5	15.1	48.1	38.6

* Adapted from Van Die et al 1979.

Table 19. Expected percentage of maximum yield for corn, oats, barley and soybeans at different planting dates in Ontario.*

Planting Dates	Corn (South-western)	Corn (Central and East-ern)	Oats and barley (South-western and Central)	Oats and barley (Eastern) and North-ern)	Soybeans (South-western, Central and East-ern
	%				
Apr 12-18	-	-	100	-	-
Apr 19-25	-	-	100	100	-
Apr 25-May 2	100	95	95	100	85
May 3-9	100	100	85	95	90
May 10-16	95	100	80	90	95
May 17-23	90	95	70	80	100
May 24-30	85	90	50	70	100
May 31-June 6	80	80	40	60	95
June 7-13	75	65	-	50	90
June 14-20	65	50	-	-	75

* Adapted from van Die et al 1979.

manure spreading operations can lead to compaction and destruction of soil structure and tilth. In Ontario it would be impractical to time all operations solely to reduce runoff and soil losses. These factors could be considered, however, when changing equipment, as increased field coverage in reduced time might result in improved timing of field operation for erosion control. It would also appear feasible to vary management to allow for increased protection of critical areas.

2.3.7 Direction of work, strip cropping and contour cropping

The direction of tillage and planting on sloping land will affect soil loss from erosion and runoff. Soil loss can be reduced 25 percent on a moderate slope with cross slope cultivation as compared to up and down slope, since water is trapped in the furrows and has more time to infiltrate. Row breakover will occur, however, if the capacity of the row to hold and infiltrate water is exceeded and the resulting soil loss will be increased as successive rows give way. In areas where row breakover is likely (ie. high rainfall intensity, low infiltration rates and/or steep erodible slopes) other measures will have to be used to prevent serious gullying.

Cross slope farming in combination with strip cropping is estimated to reduce field soil losses by up to 60 percent, as seen in Table 20. Sod strips between row crop strips slow the downslope runoff velocity, aid infiltration and retain sediment. Their effectiveness in controlling soil and runoff losses will depend on the intensity of the rain storm, slope gradient and strip widths. Their ability to protect water quality during the critical snowmelt and spring rain period is unknown.

Research in an area with shallow soils and droughty conditions showed that narrow strips, as well as being less effective for conservation purposes, could increase overall corn crop exposure to prevailing winds and result in extra moisture stress and lower yields (Stewart et al 1975).

Contour cropping involves planting rows along the contour so that water will tend to remain on the slope between rows. Although reducing downhill flow of runoff from some storms, (thereby reducing soil erosion), if rainfall exceeds infiltration and surface detention capacity breakover of contour rows will result.

Table 20. Tillage induced soil loss reductions by comparison with up-down slope farming.*

Direction of tillage	% soil loss reduction+
Across the slope	25
On the contour	50
Strip cropping across the slope	60
Strip cropping on the contour	70

+ Values from parameters used in Universal Soil Loss Equation
* Moore et al 1979.

Table 21 illustrates how differences in direction of field work can affect soil and water losses. The data indicate that contour cropping reduces soil and water loss over continuous cropping on the slope, and that the best combination for reducing soil and water loss is contour strip cropping in rotation. This combination also produced the best overall yields. Application of contouring to present cropping practices would be difficult, but a modified system combining the use of strip cropping with modified contour lines might be feasible on some farms.

Disadvantages of cross slope tillage include requirements for long gently sloping land, large fields and inclusion of hay strips for best results. These requirements are rarely all met in erosion prone areas. The practice should be avoided on steeply sloping land because of row breakover. Diversion terraces are likely to be more effective in such situations. Contouring requires large fields and simple slopes to be successful because of equipment manuverability. If the slopes are long and/or steeper than 9 percent it is not effective without the supporting practices of terracing and/or runoff diversions. Contouring provides excellent erosion and runoff control for moderate storms but is less effective than terracing or runoff diversions with intense storms.

2.3.8 Grassed waterways, terraces and diversions

Grassed waterways may be natural or the result of land forming. The channel should be smoothly contoured, broad and shallow and lined with an erosion-resistant sod. Once established it slows the runoff, prevents scouring and soil erosion in the channel and filters sediment laden runoff from the surrounding fields. Grassed waterways can significantly reduce sediments carried to streams, although the problem of rapid sediment transport out of the waterway by flood conditions (sediment flush) and its impact on water quality has not been adequately examined.

Grassed waterways must have the appropriate cross-section and be well maintained to be effective. Destruction of the grass cover by over-grazing, implement traffic or herbicides in runoff water must be prevented. Careful maintenance including frequent reseeding, may be necessary where a grassed waterway is bordered by crops requiring extensive herbicide treatment (e.g. no-till corn).

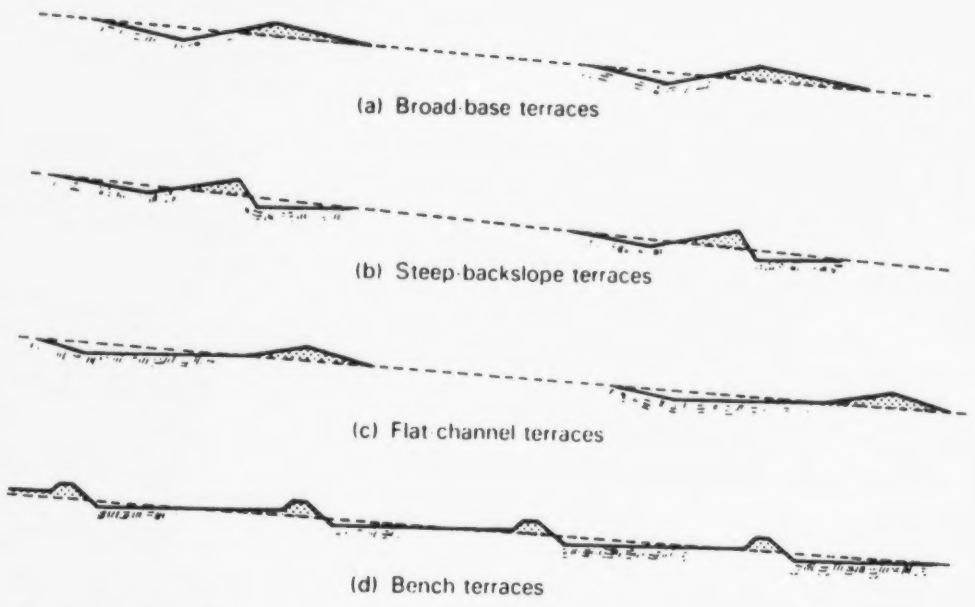
Terracing has been used in the United States to help control erosion on long slopes by shortening the slope length. Terraces intercept down hill runoff and divert it to a more stable outlet while trapping sediment in the terrace channel. Terraces are aligned across the slope and consist of a channel, terrace ridge and back slope, all of which may be cultivated if not too steep. Fig. 3 illustrates some common terrace forms. Tillage and planting are carried out parallel to the terrace.

Table 21. Average annual water and soil loss per hectare from cropped land and yields per hectare of corn, oats and alfalfa under various conditions and treatments, 1945-1957, on Rideau clay at Ottawa.*

Treatment or condition	Corn			Oats		
	Runoff (tonnes)		Yield (tonnes)	Runoff (tonnes)		Yield (tonnes)
	Water	Soil		Water	Soil	
Continuous cropping on slope	407.7	35.8	10.3	33.6	2.7	0.8
Continuous cropping on contour	152.3	6.2	14.8	-	-	1.2
Rotation on slope	103.0	10.5	17.7	78.4	1.8	1.4
Rotation on contour	89.6	7.8	22.2	67.2	3.6	1.4
Rotation on contour, in strips	15.0	1.3	22.8	9.2	0.1	1.9

Treatment or condition	Alfalfa			Alfalfa		
	Runoff (tonnes)		Yield (tonnes)	Runoff (tonnes)		Yield (tonnes)
	Water	Soil		Water	Soil	
Continuous cropping on slope	11.4	0.04	6.9	11.4	0.04	6.9
Continuous cropping on contour	-	-	5.6	-	-	5.6
Rotation on slope	38.1	0.1	6.3	13.4	0.1	8.3
Rotation on contour	9.4	0.1	5.4	9.2	0.02	6.3
Rotation on contour, in strips	16.8	0.4	5.6	10.1	0.2	6.7

* Adapted from: Ripley et al 1961.



Reference Beasley 1972

Figure 3. Terrace formations

Terrace construction requires the assistance of engineers for survey and design and for supervision of private construction. They can be excessively expensive where steep slopes are involved and regular maintenance is necessary. Among the different designs available the broad-base or flat-channel terrace (Fig. 3 (a), (c)), is probably the most adaptable. Tile outlets allow terrace alignment with existing man-made boundaries such as fences, and increase the timeliness of operations by removing excess water from the lowest points in the terrace.

Diversion ditches can be built above terraces to help channel water away from hillsides. They can protect erosion sensitive cropland from upslope runoff by permanently altering the natural drainage pattern. They differ from terraces in that they are individually designed channels and can be used anywhere along the slope. They are also used to divert water away from gullying areas and around farm building and manure storage areas.

Properly designed terraces and/or diversion ditches are very good erosion and sediment control measures, but they are expensive and use may be limited to areas with severe erosion problems. Terraces are not often cost effective even when used for high value row crops. There is a wide range in both the cost and the effectiveness of such a measure which is highly dependent on the individual farm situation (e.g. soil erodibility, sediment delivery ratio, length of slope, cropping practices, climate and type of farm). The cost effectiveness of a terrace system declines as the terrace intervals become smaller (Haith and Loehr 1979; Meta Systems Inc. 1979). Specially designed sediment traps or settling basins may also be necessary (Section 2.3.13).

2.3.9 Buffer strips

A vegetated area (buffer strip) beside a watercourse can reduce runoff velocity, prevent erosion and trap sediment before it reaches the stream, thereby protecting water quality. The width of a buffer strip is dependent on soil type, vegetation, topography and drainage area (i.e. runoff volume). Present recommendations range from 1.2 to 3 m in southwestern Ontario to 7.5 m in the sandy soils of Haldimand-Norfolk. There is at present insufficient information available to determine field-level effectiveness of buffer strips in protecting water quality from cropland runoff. In order to make an estimate Wall et al (1978) chose a 20 m buffer strip and determined that it could produce a 15 percent and 10 percent reduction respectively in sediment and phosphorus loads in several Ontario watersheds. However forest and grass buffer strips of approximately 4 m were effective in reducing levels of fecal bacteria, total soluble NH_4-N, NO_3-N, P and K in surface runoff from manure treated plots (Doyle et al 1977). There was no further significant decrease in any of the parameters for buffer strips wider than this. Buffer strips have also been proven effective in reducing pollution from feedlot runoff (Young et al 1980) (Section 4.2).

The effectiveness of a buffer strip depends partly on the type of vegetation and its condition. Proper maintenance, including occasional re-seeding, will be necessary. The Upper Thames River Conservation Authority, using information obtained from the Univ. of Guelph and elsewhere, have prepared a chart (Table 22) showing the relative degree of erosion resistance of various species.

Buffer strips subject to traffic should have a minimum width of 4 m and frequent re-seeding may be necessary to maintain a good sod cover. The buffer strip may be harvested as hay. Alternatively a narrow sod strip at least 1 m wide may be combined with a winter grain crop. This would help maximize erosion protection while maintaining a cash-crop source of income.

2.3.10 Stabilization of surface outlets, streambanks and municipal drains

Erosion of stream banks, drainage ditches and around culverts creates a problem for both farmers and water quality. In the Great Lakes Basin up to 30 percent of the stream sediment load originates from these sources (van Vliet et al 1978). It has been found to account for much more than 30 percent in watersheds with low field sediment delivery ratios and an extensive network of rapidly eroding municipal drains (Water and Earth Science Associates Ltd. 1981). Many municipal drains constructed with steep unprotected sides are poorly designed for erosion control. They carry large volumes of water efficiently but bank slumping, scouring at culverts and corner erosion are often excessive. The coarse sediment fills the channel and necessitates expensive cleaning.

Inadequate consideration is often given to erosion, sediment movement and water quality problems in present design criteria for municipal drains. Incomplete or poorly timed inspections during construction have resulted in improper use or omission of planned erosion measures. Design criteria should be improved to include protection of water quality as well as optimum water removal. Local soil and hydrological conditions should be used to determine the maximum steepness of side slopes as illustrated in Table 23.

Side-slopes can be constructed to allow mowing, with a 2:1 slope for equipment designed for bank maintenance and a flatter 4:1 slope for the typical wheeled farm tractor. Alternatively, a low growing species such as birdsfoot trefoil could be planted.

Seeding as soon as possible after work is completed provides quick establishment of a protective cover. A mulch should be applied if seeding is done during the dormant season to protect the soil and the seed until it becomes established. Surface water access should be controlled to reduce erosion and sediment transport, with interceptor ditches and/or tile lines carrying water

Table 22. Degree of erosion resistance exhibited by vegetation suitable for Ontario buffer strips.*

Variety	
Creeping Red Fescue	Highest erosion resistance
Birdsfoot Trefoil	
Kentucky Bluegrass	
Smooth Brome	
Ky. 31 Tall Fescue	
Crabgrass	increasing erosion resistance
Crown Vetch	
Reed Canary Grass	
Sudan Grass	
Alfalfa	
Small Grains	
Italian Rye Grass	Medium resistance

Note: species at the bottom provide good erosion protection, but not as good as those at top.

* Prout 1979.

Table 23. Recommended minimum side slopes for open municipal outlet drains.[1]*

Soil Materials	Minimum with bank protection[2] (vertical:horizontal)	Miminum without bank protection[2] (vertical:horizontal)
Peat and Muck	1:0.25	1:1
Clayey (35% + clay)	1:1	1:1.5
Loamy (10-35% clay)	1:1.5	1:2
Sandy or silty (10% + clay)		
Clayey or marine origin and /or banded with sand or silt (subject to low stability when satudated)[3]	1:3	1:4
Sandy or silty with high water table and/or lateral seepage	1:3	1:4

1 Cross sections can combine more than one side slope where materials change in stability or texture with depth.

2 Bank protection refers to various combinations of one or more of revetment, vegetation, buffer strips, fencing, parallel tile drains, etc.

3 Soils of marine origin (e.g. Bearbrook, Rideau and Ste. Rosalie) and others of coarse texture which are underlain by marine ("Leda") clay materials. The surface metre of these soils is often much more stable than the subsurface material.

* Modified from Anonymous, 1981b.

to controlled access points. There it should enter the ditch through erosion-preventing structures such as grass or rock-lined chutes, pipe-drop inlets, culverts or drop spillways. Buffer strips of vegetation along the bank are also recommended. Access provision for annual site inspections should be considered to assist in maintenance. Areas which include groundwater seepage or drainage outlets, sharp bends, drain junctions or road crossings are more vulnerable to erosion and should be protected by special measures such as subsurface and/or surface drains, rip-rap, gabion baskets, artificial toe protection, linings and grade control structures. Animal access along erosion sensitive waterways when the soil is wet can lead to slumping, destruction of vegetation and future erosion problems. Such areas should be fenced to limit animal access for drinking to dry periods when the banks are more stable. Drinking water can be provided by pump facilities or at specially protected stream access areas. Animal operated pumps are one solution which protects water quality without limiting water availability, although they can only be used when there is no danger of freezing. Animals should not be allowed to congregate in open water courses for extended periods or defecate directly into it.

2.3.11 Subsurface drainage

Subsurface drains can remove excess water thereby reducing overland sediment transport losses. By lowering the water table between rainfall events they allow more rain to infiltrate during spring and fall storms thereby delaying the onset of surface runoff. Tile lines parallel to municipal drains intercept groundwater seepage and help reduce bank slumping.

Subsurface drainage is expensive but improves yields as well as providing some water quality benefits. Research on a silty clay soil in Ohio showed reduction in sediment loss as the greatest benefit from tile drains. Sediment losses, averaged over all years for all crops, were about 67 percent greater for surface drainage only than from level diked plots drained by tile. Nitrate nitrogen losses were higher in tile drainage water while phosphorus and potassium losses were lower (Schwab and Kopcak 1980). However recent studies in Ontario indicated significant losses of dissolved phosphorus from tile lines under alfalfa fields (J.L.B. Culley, Land Resource Research Institute, Agriculture Canada, Ottawa, personnel communication). Tile effluent sediment concentrations have been shown to increase significantly with antecedent soil moisture content (Schwab et al 1977), a factor which may be important during spring runoff when the soil is saturated. The ability of filter wrapping of tile lines to reduce this form of sediment transport is still to be determined. The only pesticide detected in tile lines in Ontario was atrazine, however the concentration was less than that carried in surface runoff (Frank et al 1978). The overall effect of subsurface drainage on water quality cannot be assessed at this time. It would appear to reduce runoff, erosion and sediment losses, but its effect on nutrient and pesticide movement and water quality is still unknown.

2.3.12 Sediment traps and settling ponds

Properly designed sediment traps or settling ponds will reduce flow velocities and provide settling time for larger soil particles, removing them from the water transport process before they can be carried into the streams or rivers. Sediment traps are able to remove a significant proportion of the total sediment carried by runoff but are ineffective in removing the finer colloidal particles. They have little effect, therefore, on the amount of adsorbed nutrients and pesticides which are transported from agricultural fields in runoff. Sediment basins and settling ponds are most effective in small drainage areas with coarse textured soils.

They do have several disadvantages. They are costly to construct, may remove sizable land areas from production and require regular cleaning to remain effective. They can reduce drain maintenance costs by extending the life of the drain and they do have a beneficial impact on water quality when included as part of the drain design. However these benefits are not likely great enough to make them a cost effective control measure on most individual farms. Practices which prevent soil movement and transport are more cost effective at the farm level than efforts to trap soil once it has eroded off the field.

2.3.13 Removal from intensive cultivation

Areas with severe erosion problems, particularly those with excessive slopes and erosion susceptible soils, would be best seeded to permanent hay or pasture. Erosion prone land in marginal farming areas could be reforested. However it is likely that some monetary incentive would be required to promote such practices which are intended for the good of society more than the individual.

2.4 Summary

Table 24 provides a summary of erosion, runoff and sediment control alternatives. The problems of soil erosion, runoff and sediment loss will continue to cause concern, especially if the trend continues to more mono-culture row crops. Reduced soil erosion, runoff and sediment losses can be achieved when appropriate land management decisions are made. Increased extension work regarding the problems is necessary, with co-operation between the various government agencies and farm organizations. Adequate financial assistance for farmers adopting new erosion, runoff and sediment control measures should be considered, since these measures often result in a drop in net farm income (White and Partenheim 1980). Extensive use of a variety of agronomic practices to improve water quality would be preferable to legislated controls which are often hard to justify in particular situations and are often inflexible and difficult to administer and enforce (Madison et al 1980).

Table 24. SUMMARY OF EROSION, RUNOFF AND SEDIMENT CONTROL PRACTICES

Practice	Where applicable	Advantages	Disadvantages
1. No-till (zero-tillage) planting	- variable field size and slope - well drained, coarse textured soils - capital available for special equipment and possible increased pesticide costs - larger acreages available to justify newer expensive equipment required	- improved year-round erosion control because of increased surface residues - reduced runoff velocity - reduced runoff due to increased infiltration - reduced puddling and surface sealing - restricts quantity and movement of sediment - reduced field preparation time and fuel requirements	- heavy residue may delay soil warming and drying and result in poor seedling development and toxic reactions - increased use of pesticides - placement of fertilizer and pesticides limited - yield reduction on some soils - increased N demands to maintain yields because of leaching and reduced mineralization. - loss of soluble nutrients from residue greater in runoff than with conventional tillage - 10-15% more power required than with regular planters
2. Minimum tillage and residue management	- adaptable to broad range of soils - variable field size and slope	- less yield reduction than with no-till - erosion, runoff and sediment control dependent on amount of surface residue - ridge planting aids soil warming and early germination - rougher soil surface aids infiltration, reduces runoff, traps sediment - reduces puddling and surface sealing	- too much surface residue can delay soil drying and warming - increased pesticide use - reduced nutrient dispersion in soil may affect yields
3. Crop rotations	- any size farm operation, any field size - better acceptance with integrated livestock operation - suitable for cash crop enterprises only where markets available for forage and small grains.	- with legume, helps improve soil structure, infiltration - reduces soil loss and runoff - with conventional tillage, better control of some pests, more fertilizer options, no soil temperature or drying problems	- substitution of hay for corn or soybeans reduces income, especially if markets not available - higher potential for transport of soluble P although less sediment P during hay and/or small grains - some pests worse after hay - meadowless rotations do not provide much improvement in soil structure - corn-soybean sequence not recommended, produces increased runoff and sediment losses

4. Improvement of soil tilth and fertility	- any farm operation	- increased organic matter from manure, green manure and/or residues increases infiltration - better soil struture reduces soil movement and loss - improved workability of fields and higher sustained yields in long term - does not require large capital outlay for new equipment or special structures	- lost income if green manure used - increased management level required
5. Winter cover crops	- any size field - requires sufficient establishment time before winter	- cover reduces bare ground exposed to snowmelt runoff and spring rains - can prevent some N leaching - may reduce soil moisture in the spring, allowing earlier access for minimum or no-till	- timing important to get good fall growth - length of season may prevent certain crop combinations (e.g. winter wheat after grain corn) - increased cost of production if used with minimum or no-till corn, fertilizer and pesticide placement problems and reduced effectiveness of contact herbicides
6. Timing of seasonal operations	- especially important on fine textured soils	- helps maintain soil structure - increased infiltration, reduced runoff and sediment losses - choice of field practices can reduce work pressure at critical times	- in fringe areas of corn belt little room for flexibility in timing of operations - weather, drainage and/or soil texture results in reduced yields if fall ploughing omitted
7. Direction of work, strip cropping and contour cropping	- best on gentle (2-7%) slopes, large fields - strip widths and equipment size must be compatible - contour cropping best on moderate length, simple slopes, large fields	- cross-slope cropping prevents downhill channelization of runoff - sod strips slow runoff, protect soil, and filter out sediment - increased infiltration of water - can reduce erosion over short distance if rainfall not excessive - reduced runoff during gentle rainfalls	- can slow down field work - hay required in strip cropping for best results, requires proper fertilizer application and market - may increase soluble nutrients in runoff - shallow soil and droughty conditions allow winds to further dry out strip cropped corn, reducing yields - steeper slopes and large equipment are incompatible - contour cropping not compatible with complex slopes - time consuming to lay out contours - requires terraces for longer slopes - if breakover occurs can increase runoff and sediment loss

Table 24. SUMMARY OF EROSION, RUNOFF AND SEDIMENT CONTROL PRACTICES (Con't.)

Practice	Where applicable	Advantages	Disadvantages
8. Grassed waterways, diversions, terraces	- natural depressions and channels where water tends to collect and move over field - farm operations where loss of land and expense of construction not a major deterent - large fields required to reduce cut-up effect.	- reduced runoff velocity decreases erosion - sediment deposition likely - prevents soil erosion on susceptible slopes	- cost of construction - loss of land from production - maintenance of grassed waterways difficult if herbicides used - inconveniences when working fields
9. Buffer strips	- beside open watercourses	- helps reduce runoff velocity, may increase infiltration, helps trap sediment - slower runoff less likely to to erode banks into stream - sorption of nutrients and pesticides before they reach waterway	- requires proper establishment and maintenance - loss of land - some shrubs and trees used to stabilize soil can reduce crop growth nearby - altered herbicide programs to prevent loss of hay buffer strips
10. Stabilization of surface outlets, streambanks and municipal drains	- farm land abutting an open water course	- bank stabilization will prevent erosion back into farmland and destruction of culverts - eventual reduction in maintenance costs of outlet drains - prevents undercutting of culverts and fence rows - vegetated strips provide entrapment of sediment, reduction of runoff velocity and better infiltration	- some loss of land - additional cost of vegetating ditch banks and installing structural protection - fencing cost to limit livestock access - cost of providing alternate watering facilities for livestock
11. Subsurface drainage	- where poor natural drainage or high water tables hinder downward water movement - less effective and more expensive in fine textured soils	- lowers soil water content between storms allowing more infiltration - increased storage capacity delays start of runoff - less sediment movement on surface - extends working season and reduces soil compaction during tillage and harvest - increased yields	- may increase nitrogen and soluble pesticide leaching - soluable 'P' movement within tile lines - initial capital cost - full impact on water quality not currently known

12. Sediment traps and setting ponds	- most effective in small drainage areas with soils of low clay content but high erodibility	- reduces sediment load of large particles	- cost of construction - unable to trap finer particles and attached contaminants - removes land from production - frequent maintenance required to prevent reduced efficiency from sediment accumulation
13. Removal from intensive cultivation	- severe erosion prone lands - marginal farmland near streams	- stabilize erosion problem - cover can slow runoff, increase infiltration, trap sediments and sorb nutrients and pesticides from cropland	- loss of land for income production - cost of establishing either a protective sod or tree cover

3. NUTRIENTS

3.1 Introduction

Pollution of water by nutrients reduces its palatability, increases health risks to humans and livestock and may also accelerate eutrophication. Pollution by domestic sewage and industrial waste has long been recognized as a serious threat to the quality of our water. More recently it has been suggested that nutrients from decaying plant residues and soil-applied fertilizers or manures often find their way into water systems. This possibility is of particular concern for nitrogen and phosphorus (Stewart et al 1976).

For nitrogen the most common problem is toxicity associated with nitrogen levels in drinking water in excess of 10 mgN/L (as nitrate plus nitrite). The nitrite form of nitrogen is the most toxic as it interacts with blood components and interferes with oxygen transport, a condition known as methemoglobinemia. Infants are particularly susceptible and water for a child under a year should contain less than 1.0 mg/L of nitrite (or less than 10 mg/L of nitrogen in nitrate form) (McNeely et al 1979). Since nitrite is unstable in the presence of oxygen the problem so far has been associated mostly with anoerobic conditions. Unsafe nitrite levels have been detected in farm wells with faulty well casings and/or located close to manure storage areas (Stewart et al 1976). Excessive use of nitrogen fertilizers could eventually result in contamination of ground water aquifers affecting large areas. Nitrate is 5 to 10 times less toxic than nitrite. Cattle, young animals and children, however, convert some nitrate to nitrite in their gastric systems and can develop methemoglobinemia (Stewart et al 1976). Excessive nitrate levels in farm water supplies can interfere with conception and reduce the number of live births in farm animals. Nitrogen in the form of dissolved ammonia is toxic to fish. Trout, one of the most sensitive species, are affected by levels of 1-2 ppm (Stewart et al 1976). Lake eutrophication due to nitrogen is not, however, a problem in the Great Lakes. Although it is required for aquatic plant growth, it is rarely the limiting factor (Dobson et al 1974; Neilsen et al 1978).

Phosphorus, on the other hand, does not generally create toxicity problems even at elevated levels; however it does promote excessive aquatic plant growth. The excessive algal growth and its subsequent death and decay clogs water intake filters, causes unsightly and fouled beaches and depletes oxygen in lakes and streams resulting in the death of fish and aerobic organisms, foul odours, and bad tastes in water supplies. The water becomes unsuitable for domestic and industrial water supplies, commercial fishing, recreation and wildlife. The PLUARG study group looked at all aspects of non-point sources and land drainage and found that in 1976 Canadian agriculture contributed approximately 3000 tonnes of total phosphorus to the Great Lakes, of which about 40 percent was in dissolved readily

available forms. The importance of the agricultural contribution relative to other sources varied from lake to lake. The major (70 percent) agricultural source of phosphorus was cropland. Agricultural lands most likely to be a source of phosphorus pollution in water courses were; 1) those with a high clay content used to grow row crops and 2) those receiving large applications of phosphorus from fertilizer or manure. Livestock operations contributed phosphorus, mainly as dissolved P, at rates averaging 20 percent of the total agriculture load (Coote et al 1978). This estimate includes direct runoff from livestock holding facilities, manure storage areas and manure spread on frozen ground.

One of the goals of the 1978 Canada-U.S. Great Lakes Water Quality Agreement is the reduction of phosphorus levels entering the Great Lakes, to assist in the restoration and maintenance of Great Lakes water quality. Some reduction in the agricultural contribution is necessary, especially for Lakes Erie and Ontario, to achieve the target loads.

3.2 Importance Of Management Decisions

Nutrient losses are caused by a variety of transport processes which vary in importance with the time of year, with the nutrient under consideration and with its chemical form. These different transport processes must be understood if nutrient losses are to be reduced. Nitrate-nitrogen, being highly soluble, is easily leached or lost in runoff, while ammonium is fixed by, or adsorbed to, the soil and more apt to move with soil loss (Stewart et al 1976). PLUARG studies showed that the sediment associated portion accounted for 25-30 percent of the total nitrogen lost (Neilsen et al 1978). Nitrogen losses are greater when the soil organic matter content is high (Stewart et al 1976). Phosphorus losses are primarily through erosion, since the main form of phosphorus transported is phosphate which is adsorbed strongly by soil particles. Soluble forms of phosphorus are lost in runoff water and in tile drainage effluent (Bolton et al 1970; Bolton and Hore 1976).

The actual movements of nitrogen through the environment are not clearly defined. Nitrogen can enter watercourses in soluble forms, either in surface runoff or in subsurface flows, and in insoluble forms in association with organic matter or sediment. The relative importance of these processes varies with the crop, the location, season and climate. Burwell et al (1977) found that the amount of water soluble N lost in runoff was low compared to the amount of N applied and used annually by the crop. Neilsen et al (1982) found that water soluble N losses in runoff were highest during the Feb.-March period in Ontario, while research in Iowa (Schuman et al 1973) indicated such losses were highest at the start of the crop year. Seasonal variations in nitrogen losses for each region must be considered when determining fertilizer practices and runoff control measures for nitrogen. This is especially important in Ontario where snowmelt and spring rains play an important part in soil and water losses (Spires and Miller 1978; Neilsen and MacKenzie 1977; Neilsen et al 1978).

Snowmelt runoff in southwestern Quebec and southeastern Ontario transported annual soluble nitrogen loads during March, April and May (Neilsen and MacKenzie 1977).

Burwell et al (1975) looked at the effect throughout the year of five soil cover treatments (ranging from hay in rotation to continuous clean cultivated fallow) on the nutrient content of surface runoff in west-central Minnesota. They found that most annual losses of sediment-bound nutrients occurred in the two months immediately following corn planting, after fertilizer had been added and the soil was bare and unprotected. On the other hand much of the annual water and soluble nutrient loss was accounted for by snowmelt runoff. Further study (Burwell et al 1977) showed that when recommended fertilizer rates were used total N and P losses to streams were less than 16.1 percent and 1.5 percent, respectively, of that applied. Nutrients can be leached out of plant residues by repeated freeze-thaw cycles and carried into streams by snowmelt runoff and spring rain. Residue leaching is not considered a serious problem at present, however, when compared to potential nutrient losses associated with nutrient inputs used in continuous monoculture farming (Stewart et al 1976). Nutrients also enter water systems from materials naturally present as part of the soil. An example of the percentage of total nutrient inputs to cropland represented by plant residues is shown in Table 25.

Ontario research (Neilsen et al 1978) has shown a positive correlation between stream N concentrations and inputs of fertilizer and manure to the watershed. Fertilizer nitrogen inputs (amounts and timing) should be tailored to crop requirements and managed to achieve optimum plant uptake. This is obviously true from the standpoint of production and economics, but it is equally important from the standpoint of environmental quality.

Groundwater nitrate levels can also be raised if excessive nitrogen fertilization occurs (Johnston et al 1965, Schuman et al 1973). Elevated groundwater nitrogen concentrations have resulted under Canadian conditions (Bolton et al 1970; Nicholls and MacCrimmon 1974; Miller 1979) especially after application of fertilizer nitrogen above recommended rates (Miller 1979). Research on a clay soil, (Bolton et al 1970) showed that drainage effluent from fertilized corn following alfalfa and from second year alfalfa contained nitrate nitrogen values in excess of 10 ppm NO_3-N. The high nitrogen concentrations found in the drainage waters were from nitrogen produced and stored by the alfalfa and from the nitrogen fertilizer applied to the corn. Table 26 shows the effects on water quality of fertilizer usage above recommended rates. Nitrogen application at or below the recommended rates had little detrimental effect on the tile effluent. Substitution of manure for inorganic fertilizer and use of heavy applications can likewise result in elevated groundwater nitrate levels (Patni et al 1981). On organic soils nitrate levels in the tile effluent were very high and in some seasons were more than double the amount of fertilizer nitrogen added (Miller 1979). This was attributed to mineralization and subsequent release of the organic nitrogen.

Table 25. Sources of nitrogen and phosphorus for crop production on a United States and a watershed scale.*

	United States		Wisconsin watersheds	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
TOTAL ADDITIONS TO SOIL	13.5 million tonnes	2.7 million tonnes	131 kg/ha	28 kg/ha
Source	Percent	Percent	Percent	Percent
Fertilizer	45.9	76	8.5	32
Fixation	20.3	0	10.3	0
Manure	6.8	14	35.9	48
Plant residues	16.9	10	38.5	20
Precipitation	10.1	0	6.8	0

* Adapted from Stewart et al 1976.

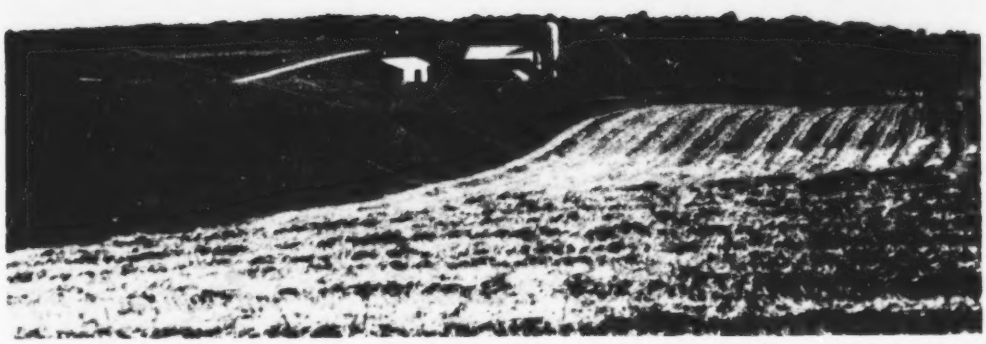
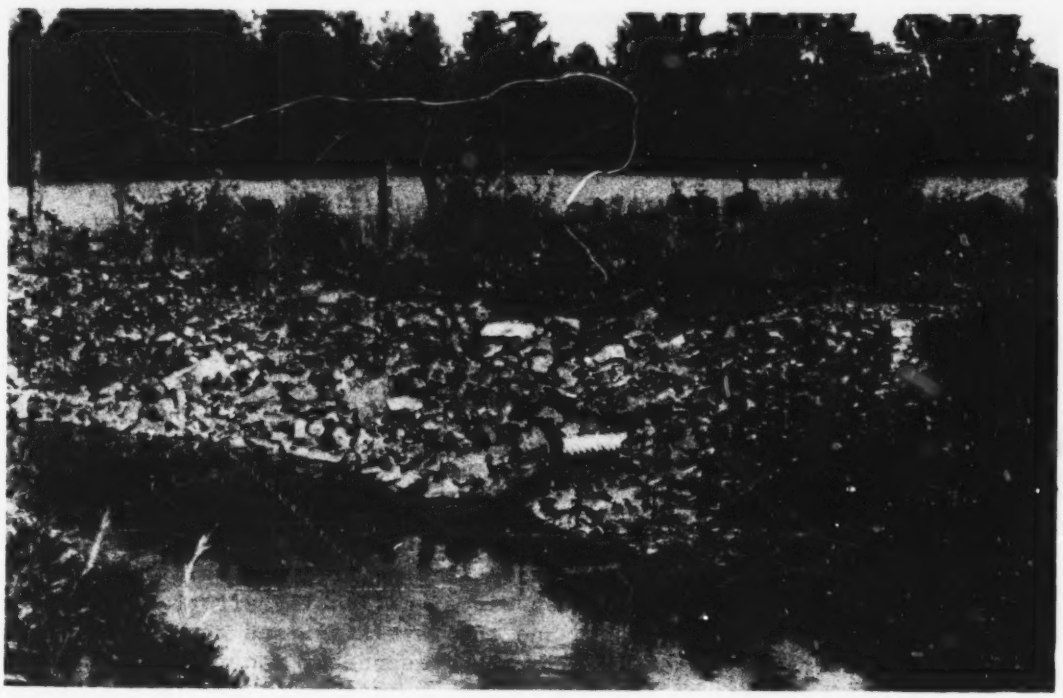


Table 26. Annual average concentration and total content of NO_3-N in tile drainage water from six mineral soil sites in relation to fertilizer use.*

Site Number Dover Twp. Kent County Ont.	Texture	Average N+		Average NO_3-N conc.		NO_3-N content	
		Applied	Recommended	1972	1973	1972	1973
		kg/ha		mg/liter		kg/ha	
5	Clay	110	85	17.5	14.0	64	50
6	Clay	35	50	6.4	5.5	16	17
7	Sand	92	104	8.2	7.9	14	16
8	Sand	150	130	6.3	4.4	4	3
9	Clay	110	130	4.7	4.0	12	4
10	Sand	200	150	20.4	11.3	49	61

+ Weighted average by crop during 1970-1973 period.
* Miller 1979.



No single transport process or time of year is most important under all conditions - clearly it is important to attempt to minimize N losses from each of these processes and incorporate management practices which attempt to control all forms of N loss.

Control of phosphorus, usually categorized as a strongly absorbed nutrient, has been thought to be closely associated with reductions in erosion and sediment transport. Ontario research found that approximately 60 percent of the total phosphorus in runoff was associated with sediment (Miller and Spires 1978). Practices which reduce erosion (eg. no-tillage, conservation tillage, sod-based rotations, contouring, terraces, etc.) can significantly reduce sediment associated phosphorus losses (Haith and Loehr 1979). Estimated total phosphorus reductions which could be achieved with Level 1 remedial measures (Page 3) in four of the PLUARG agricultural watersheds ranged from 36 percent in the Little Ausable River to 50 percent in Holiday Creek (Miller and Spires 1978).

The reduction in nutrient losses is always less than the reduction in sediment loss (Stewart et al 1976, Logan 1978). This is because nutrients have a high affinity for the fine-textured soil particles and these can not be completely controlled by most of the runoff and sediment control measures. The most effective approach is to reduce the detachment of soil particles at the field, especially on clay soils since clay is more easily controlled at its source than in transport (Walter et al 1979). Practices which reduce gross erosion do not, however, produce an equivalent reduction in phosphorus loadings. The Maumee River basin studies in Ohio suggested that erosion reducing practices reduced phosphorus loadings by 60-90 percent of the percentage reduction achieved for gross erosion (Logan 1978).

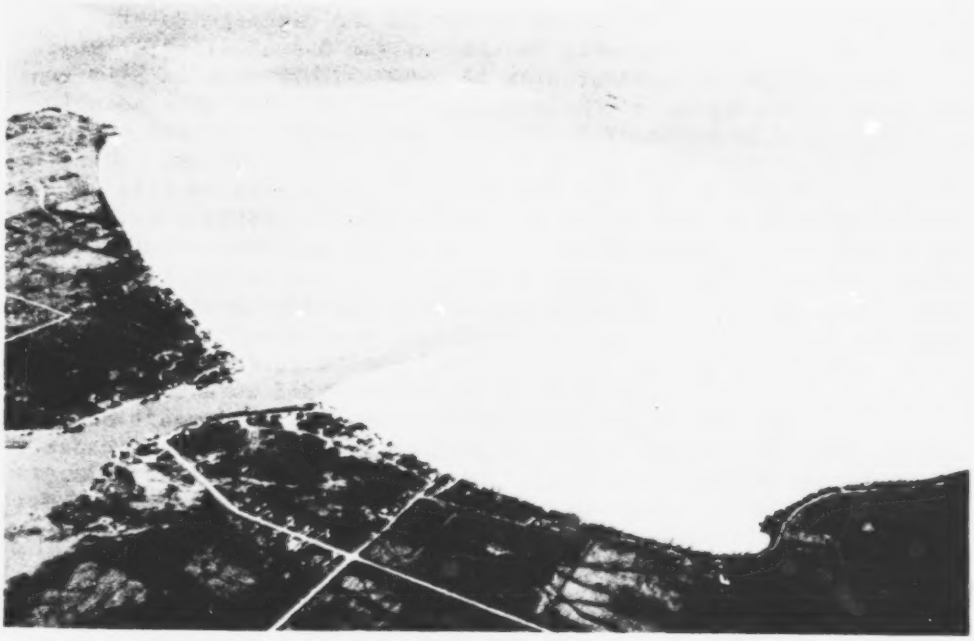
Phosphate fertilizer additions can increase losses from both soluble phosphorus and sediment associated phosphorus. The soil particles are enriched by the availability of more phosphorus, and the degree of enrichment is affected by the degree of incorporation. When phosphate fertilizers are left on or near the soil surface, the available P lost with the sediment is higher than when the fertilizer is plowed under (Baker et al 1979). Phosphate fertilizer applications should always be matched to the crop requirements to help reduce unnecessary soil enrichment and nutrient losses.

Sediment phosphorus was once considered the main source of phosphorus in runoff. However during the PLUARG work it became apparent that dissolved phosphorus in cropland runoff could account for a considerable portion of the phosphorus load. Surface runoff from selected Ontario agricultural subwatersheds contained dissolved phosphorus levels ranging from 25-60 percent with an average of 43 percent of the total P. Table 27 shows the significance of the dissolved P for the southern Ontario portion of the Great Lakes. The dissolved phosphorus portion was significantly affected by the percent clay in the watershed and the fertilizer and manure phosphorus added (Miller and Spires 1978). The presence of manure or fertilizer on the soil surface at the time of the runoff event markedly increased

Table 27. Total annual loadings of total phosphorus and total dissolved phosphorus due to agricultural activities in the Southern Ontario portion of the Great Lakes Basin as estimated by regression equations.*

Watershed area	Total phosphorus loading Tonnes	Total dissolved phosphorus loading Tonnes	Dissolved P / Total P %
Georgian Bay	180.9	78.8	44
Lake Huron	596.6	296.4	50
Lake Erie	1578.4	580.7	36
Lake Ontario	639.1	236.6	37

*Miller and Spires 1978.



the dissolved phosphorus concentrations. Fertilizer and manure phosphorus inputs should follow the recommended rates since they increase the 'available' phosphorus disproportionately and therefore present a greater risk to water quality. Fertilizer and manure use on agricultural land was not considered a major source of Great Lakes pollution (IJC 1978), although it can cause serious localized water quality problems.

Soluble phosphorus losses were also more important when sediment concentrations in the runoff were less than 1000 mg/L. At sediment concentrations below 100 mg/L as much as 90 percent of the total P in the runoff was in solution (Spires and Miller 1978). Control methods for reducing soluble phosphorus losses (eg. runoff reduction, manure and fertilizer incorporation etc.) will become increasingly important as erosional losses of sediment bound phosphorus are reduced.

Movement of soluble phosphorus through the soil and into streams via tile effluent has previously been considered minimal. Burwell et al (1977) and Schwab et al (1973) found only a very small percentage of applied phosphorus appearing in subsurface discharge. Results of a study on an Ontario clay soil (Brookston) indicated that phosphorus concentrations in the effluent from all crops, although low, were frequently above that required for eutrophication. Higher values were present from corn fields and the lowest came from bluegrass sod. Fertilizer application did produce a small but consistant increase in dissolved phosphorus levels in the drainage water. The predominant factor influencing losses was the amount of water which flowed through the soil (Bolton et al 1970). Work done on an organic soil in 1974 (Nicholls and MacCrimmon) also indicated more soluble reactive P in tile effluent from cultivated fertilized plots than from unfertilized plots, probably as a result of fertilizer use. They concluded, however, that such losses were likely rare in tile effluent. Miller's study (1979) on the effect of intensive cropping on nutrient losses in tile effluent showed that the concentrations of dissolved phosphate phosphorus and total phosphorus in the tile effluent from mineral soils were low and were considered insufficient to lead to deterioration of water quality. Drainage water from organic soils however, contained very large amounts of phosphate that were high enough to cause serious water quality problems and were related to very high fertilizer phosphorus applications. The amount of leachable phosphorus was inversely related to the P-sorption capacity of the organic soil.

Schwab et al (1973, 1977) and Schwab and Kopcak (1980) showed that (i) increased percolation of water through a silty clay soil increased phosphorus leaching and (ii) the soil had a tendency to desorb phosphorus. The phosphorus desorption decreased with depth but increased with phosphorus application rates. Although mineral soils in Ontario have a large phosphorus sorption capacity these results suggest that it may be necessary to limit phosphorus applications to crop requirements to maintain the quality of tile drain effluent. More research is required, however, to evaluate the impacts of phosphorus fertilization on soil phosphorus build up versus maintenance and the effect such practices have on water quality.

3.3 Nutrient Management Practices for Improved Water Quality

3.3.1 Matching nutrient supply to crop requirements

Emphasis should be placed on nutrient management to ensure efficient crop uptake and utilization. This is especially important in areas with a high risk of eroded sediment and runoff being transported to streams. Soil testing to determine the requirement is a useful tool and could result in a reduction in phosphorus fertilizer use. Data from PLUARG and the Ontario Soil Testing Service indicate that, on the average, fertilizer P additions exceed recommended requirements for all crops except hay and pasture. The greatest excess occurs with vegetable crops, followed by tobacco and corn (Miller and Spires 1978). A growing crop can utilize nutrients from indigenous sources or from applications of fertilizer, manure, or sludges. When nutrient levels, from either natural or applied sources, exceed crop requirements the unutilized nutrients can be carried from the field in runoff, or leached down into the ground water. Plant nutrient applications should be matched to the crop requirement and should achieve the optimum return per hectare. This is not necessarily the same as maximum yield per hectare. Ontario soils generally have above average phosphorus concentrations and further additions can often be unnecessary and uneconomical, as well as creating a potential water quality problem (IJC 1978).

Fields which are low in phosphorus can be built-up with good fertilizer management and cropping practices, and then maintained at that level. It is uneconomical to continue to build up soil phosphorus levels beyond those required for optimum dollar return per hectare since much of the excess phosphorus can be removed by erosion, runoff and leaching.

Nitrogen overfertilization should also be avoided since it has been associated with elevated stream nitrogen levels (Nielsen et al 1978). It does not appear to be a common practice in Ontario. There is no soil test for nitrogen and current recommended rates are based on field experience. There is speculation that this may result in excess nitrogen applications on soils with high organic nitrogen contents and high net mineralization rates. More research is required in Ontario on the availability of nitrogen from these natural processes. Until researchers understand the nitrogen cycle better it will be difficult to determine the level of nitrogen fertilization best for these soils from both a cropping viewpoint and a water quality outlook.

3.3.2 Application method and fertilizer form

Incorporation of organic and inorganic plant nutrients plays a significant role in reducing nutrient losses as well as increasing plant uptake efficiencies. Conventional tillage (i.e. fertilizer plowed under) can result in smaller losses of soluble phosphorus and nitrogen compared with conservation tillage methods even though soil and water losses are higher. Failure to incorporate fertilizer

or manure into the soil has resulted in high concentrations of soluble phosphorus in the runoff even when soil erosion was reduced (Römkens et al 1973). Timmons et al (1973) found that incorporating fertilizer nutrients with plowing followed by discing effectively minimized nutrient losses while broadcasting fertilizer on a disced surface resulted in high nutrient losses in the runoff. Whitaker et al (1978) found that incorporating the major N application into the soil 5 to 6 weeks after planting not only reduced runoff losses but allowed more efficient use of N by the crop. Incorporation of manure as soon after spreading as possible likewise reduced nutrient losses (Neilsen et al 1978; Miller and Spires 1978).

Split applications of nitrogen, (i.e. supplying nitrogen at two or more times of the year when crop uptake rates are high), are more economical and efficient than one heavy application. Corn, for example, exhibits little nutrient uptake until 3 or 4 weeks after emergence (Stewart et al 1975). Split applications also decrease the likelihood of nitrate leaching beyond the root zone and the toxic effects of excessive fertilizer near young plants. Timeliness is still important however, to prevent yield reductions. Fall fertilizer applications are undesirable in Ontario, even though convenient for farmers and suppliers. Late fall rains, snowmelt and early spring rains can remove much of the nitrate before crop utilization is possible. Incorporation of ammonium fertilizers when soil temperatures are below 10°C (50°F) can reduce this nitrogen loss. Slow-release nitrogen is another alternative although more research is needed since experiments in south-western Ontario have shown that nitrogen is often still available for leaching after the crop season ends (Beauchamp 1977).

Soil incorporation of fertilizers is incomplete on no-till or minimum till fields. Dry top dressed fertilizers such as urea require rain to move the nitrogen into the root zone. Unfortunately excessive rain may remove it in runoff or leach it below the root zone. Nitrogen uptake efficiency can be increased by banding instead of surface broadcasting (Whitaker et al 1978). Choice of fertilizer used in a residue management system requires careful consideration of soil type, amount of residue, moisture conditions and equipment availability. Further reductions in nutrient losses and localized water quality problems can be achieved by limiting fertilizer applications in areas adjacent to streams and ditches. Winter spreading of manure should also be done away from ditch banks, streams and runoff channels to prevent direct entry of nutrient contaminated runoff into stream water (Section 4.3.4). Guidelines have also been established on when and where sludge may be applied (Section 6.1).

3.3.3 Crop rotations

Crop rotations can reduce overall watershed nitrogen applications by combining the production of crops with high nitrogen requirements (corn), medium nitrogen requirements (small grains, grasses) and low fertilizer nitrogen requirements (soybeans, alfalfa and other legumes). Legumes often require no additional nitrogen since they fix nitrogen from the atmosphere. Less nitrogen is available

within the soil for leaching below the root zone and root decomposition supplies nitrogen for subsequent crops. Deep-rooted crops such as alfalfa can utilize nitrates which have leached below the rooting depth of other crops, further reducing the potential for groundwater pollution (Stewart et al 1975).

3.3.4 Use of animal manure and green manure crops

Plant available nitrogen in manure is released slowly allowing more efficient uptake during crop growth. This reduces the amount of nitrate available at any one time during the growing season. However heavy manure applications can result in more nitrogen released, both before and after harvest, than can be utilized by plant uptake. The unused nitrogen becomes a potential hazard to groundwater supplies.

The nutrient value of a manure is variable, depending on animal type, age, feed, litter and storage. A chemical analyses is necessary to accurately determine the nutrients available for the crop. Table 28 illustrates how manure can replace or supplement commercial fertilizers under a variety of conditions. The feasability of completely replacing fertilizer with manure is illustrated in Tables 29 and 30. Soil testing is important, however, to define the maximum environmentally safe loadings for manure applications and to ensure that nutrient imbalances are not created. A value can be placed on manure based on nutrient availability and reduction in commercial fertilizer requirements. Manure use can result in economic benefits, provided certain precautions are taken (Section 4).

Green manuring (plowing under a growing crop) supplies a source of slow release nitrogen for future crops. It is a good method of returning nutrients to the soil, helps improve soil organic matter and can increase yields. Legume crops, used as green manure, supply more nitrogen than that available from other crops and can reduce fertilizer costs.

3.3.5 Winter cover crops

Winter cover crops (e.g. winter cereals, red clover) can protect water quality. Soluble inorganic nitrogen left unused by the previous crop is utilized by the cover crop until freeze-up, thereby reducing losses associated with downward leaching and surface runoff during the Dec. - Mar. high volume runoff periods (Neilsen et al 1978). Spring losses are also reduced, as the crop begins nitrogen uptake as soon as growth commences.

Timing of the operation and economic feasibility are important when considering use of a winter cover crop. Following a late season crop (i.e. grain corn) there is usually insufficient time for adequate growth of the cover crop before winter, unless it is planted

Table 28. Recommended reductions in fertilizer application where manure is applied +

Solid Manure		Liquid Manure		Subtract from Fertilizer Requirement +				
				Nitrogen N(kg/ha)			Phosphate	Potash
tonnes per hectate*	tons per acre*	cubic metres per hectare**	gallons per acre**	F & W	Spr	Spr C***	P_2O_5(kg/ha)	K_2O(kg/ha)
			Cattle or Mixed Livestock Manure					
20	9	50	4400	25	50	60	20	90
30	13	75	6700	40	75	90	30	135
40	18	100	8900	50	100	125	40	180
			Swine Manure					
20	9	30	2700	25	50	60	25	35
30	13	45	4000	40	75	90	35	50
40	18	60	5300	50	100	125	50	70
			Poultry Manure					
4	2	10	900	20	45	60	25	22
10	4	25	2200	50	110	140	60	44

* 66 bu manure = 1 metric tonne, approximately. 10 tonnes/ha = 4.5 ton/acre.
** One cubic metre = 220 imperial gallons. One cubic metre per hectare = 90 gallons per acre.
*** F & W denotes fall and winter applied manure;
Spr denotes spring applied and not covered immediately including surface applications after seeding;
SprC denotes spring applied manure covered immediately after application.

+ These values assume that for manure applied in the spring and not immediately worked in, 50% of the nitrogen (75% for poultry manure), 40% of the phosphate and 90% of the potash are as available in the year of application as the nutrients in manufactured fertilizer. Appreciable portions of the nitrogen in manure are lost to the air after field spreading unless manure is immediately covered with soil. Some of the nitrogen and most of the phosphorus not available to the crop in the year of application are in organic form and become available gradually in later years.

+ Anonymous, 1981a.

Table 29. Corn yield response to beef manure (1972-75).

Added Fertilizer	Manure (tonnes/ha)			
	0	11.2	22.4	44.8
	yield (t/ha)			
None	4.4	5.9	6.1	6.6
50-50-50	7.1	7.2	7.0	7.0

Baldwin 1976.

Table 30. Corn yield response to swine manure (1972-75).

Added Fertilizer	Manure (tonnes/ha)			
	0	11.2	22.4	44.8
	yield (t/ha)			
None	4.4	5.9	7.0	8.1
50-50-50	7.1	7.6	7.4	8.0

Baldwin 1976.

by aerial seeding into the standing crop. In areas where a legume can be established, it can reduce nitrogen fertilizer requirements for the next production period (Mitchell and Teel 1977). When non-legumes are used as a cover crop, extra nitrogen may be required to help break-down the cover crop residue.

3.3.6 Erosion, runoff and sediment control

Nutrient losses from agricultural land can also be reduced with the remedial measures outlined in Section 2.3.

3.4 SUMMARY

A summary of nutrient management practices is shown in Table 31. Nutrient losses from farmland, particularly phosphorus, will have to be reduced if the water quality of the Great Lakes is to meet proposed standards set out in the 1978 Canada-U.S. Great Lakes Water Quality Agreement. Phosphorus losses, of which 60 per cent are sediment bound, can be reduced best by erosion and runoff controls (i.e., conservation tillage, buffer strips, strip cropping, contour cropping etc) which decrease sediment transport. Reduction in soluble phosphorus losses from agriculture are also important since this fraction is immediately available for uptake by aquatic plants. Proper fertilizer and manure management practices such as application to meet crop needs, proper placement, timeliness and incorporation as soon as possible will help control these losses.

Nitrogen additions to the Great Lakes from agriculture are not considered a serious Great Lakes water quality problem since lake concentrations are well below toxic levels and nitrogen is rarely a limiting nutrient in eutrophication. Nitrogen losses can, however, result in localized water quality problems if concentrations are elevated above recommended safe drinking standards. Nitrogen applications should be timed to coincide with the period of maximum crop uptake to maximize efficiency. Careful selection of efficient cropping programs which reduce overall nitrogen requirements, utilize residual soil nitrogen and reduce runoff and sediment loss will reduce the likelihood of water quality degradation by nitrogen.

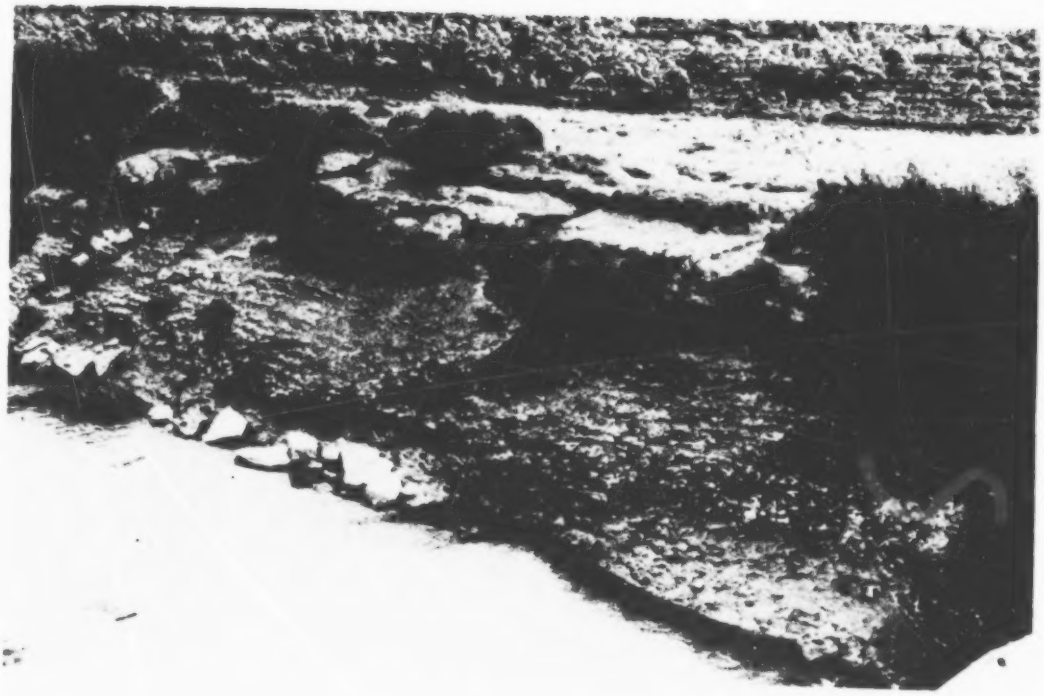


Table 31. SUMMARY OF NUTRIENT MANAGEMENT PRACTICES

Practice	Where applicable	Advantages	Disadvantages
1. Regulating nutrient supply to meet crop requirements	- all farms - number of samples/field required for soil testing dependent on variability of soil	-prevents excessive fertilizer use -reduces leaching and runoff losses to water -prevents nutrient imbalances from developing in soil which might reduce crop yield -reduces costs of unnecessary fertilizer applications	-time consuming if done properly -difficulty in doing soil testing at appropriate time
2. Application method and fertilizer form	- all farms - more feasible if labour available during spring season	-reduces leaching losses -incorporation reduces surface runoff losses -maximizes plant uptake	-second field pass required if split application -if weather delays application, could reduce yields
3. Fertilizer use (inorganic and organic)			
(a) incorporation into soil	- not limited by farm or field size - difficult when no-till used - minimum till can reduce opportunities for incorporation	-decreased nutrients lost in runoff -can increase plant uptake efficiency -will not reduce yields or injure crop if properly applied	-often difficult due to time constraints and weather problems -may increase costs if equipment or labour required for job
(b) Proper management in highly sensitive areas, and/or when incorporation not possible	- flood plains, areas in hay or pasture, minimum till, or no-till	-reduce losses during runoff from snowmelt, flood periods, and on minimum and no-till fields	-income losses through reduced yields if timing prevents application, or weather reduces efficiency of late applications
(c) not applying fertilizer or manure during sensitive periods	- land bordering watercourses - snow covered or frozen ground adjacent to open water or in flood zones during flood seasons	-reduced loss of nutrients in spring runoff and flood periods -better use made of fertilizer applications, improved yields	-weather and timing difficulties could mean yield reductions -increased difficulties with manure storage and use -may require additional costs in equipment, labour and time for best use of manure

4.	Crop rotations	-no physical limitations -market availability will affect economic feasibility	-reduced nitrogen input if includes crop with low nitrogen requirements -reduced leaching possibilities protects groundwater -rotations reduce pesticide requirements -legume nitrogen improves crop yields in following year, reduces nitrogen available for leaching downward -helps soil structure, reduces erosion, maintains organic matter	-reduced income if no market for crop -some nutrients lost in spring runoff from leached plant residues -rotation sequence can limit desired herbicide applications, may result in lowered yield if poor weed control obtained
5.	Use of animal manure and green manure crops	-any farm -restricted by availability of animal manure -restricted use necessary at time or place which would facilitate stream entry of animal manure	-reduces commercial fertilizer needs -provides a source of slow release N, reduces leaching -increased organic matter and improved soil structure -reduced erosion and soil loss	-with animal manure, time required to spread, more inconvenient -should be incorporated in soil to prevent runoff losses, timing a problem -loss of cash crop income when green manuring -if spring plowed, can delay seeding, reduce yields -nutrient release over period of no growth.
6.	Winter cover crops	-no physical restrictions -may be more difficult in cash crop operations	-continued use of nitrogen in soil in late fall, reduces amount available for over winter leaching -split nitrogen application means less N in ground over winter -can use soil water and nitrogen early in spring therefore delays onset of leaching	-may not fit into cash crop operation without reduction in income -requires early fall harvest to allow soil preparation and crop establishment
7.	Erosion, runoff and sediment controls	-see Table 24	-reduced loss of sediment bound phosphorus and nitrogen and soluble nutrients in runoff -improved soil structure	-see Table 24 -most likely related to cost and loss of land from production

4. LIVESTOCK MANURE

4.1 Introduction

Livestock enterprises have grown larger over the last few decades with more animals being kept per unit area. In many instances the quantity of manure produced has resulted in both practical and environmental problems relating to the site location, type of storage and the ultimate utilization and/or disposal of the manure. A hundred-cow dairy herd produces 165 metric tons/year (dry weight) of manure (Long 1979), and one steer of 453.6 kg can produce 7.7 kg/day of urine and 19.5 kg/day of semi-solids (Loehr 1968). Table 32 gives an indication of both the total amount of manure as well as the nutrients excreted by different farm animals in a day.

The physical and chemical properties of manure are controlled by the amount and kind of feed consumed by the animal and the efficiency of conversion. This is largely determined by feed quality which affects both the amount consumed and the chemical composition of the manure, since proteins, which contain most of the nitrogen, vary considerably in digestibility (Black 1967).

Many studies have been undertaken describing the effect of manure and manure runoff relative to water quality problems (McQuitty et al 1971; Black 1967; Townshend et al 1970; Loehr 1974; Gilbertson et al 1971; Patni and Hore 1978; Beak Consultants 1977; Coote and Hore 1978; Robinson and Draper 1978). The entry of animal manure or its runoff into ground or surface waters can degrade water quality because of: (i) excessive nutrients (N and P); (ii) high ammonia levels which result in fish kills; (iii) high biological and chemical oxygen demands (BOD and COD) which can deplete oxygen levels (especially during periods of low flow and elevated temperatures); and (iv) microorganisms which may impair the use of surface waters for both recreational and consumptive use.

The nutrient problem is a result of both the amount of manure which can be produced and the mobility of its constituents. Runoff from manure piles and feedlots can transport high concentrations of soluble nitrogen and phosphorus. The actual quality of the runoff is highly variable however, depending on animal density, management practices, feed rations, and site characteristics (e.g. soil topography, soil moisture and rainfall intensity) (Loehr 1972; Task Committee on Agricultural Waste Management 1978).

The problem with ammonia is related to its toxicity. Direct entry into open water of manure with ammonia levels as low as 0.02 mg/L (as the un-ionized NH_3) can be detrimental to freshwater aquatic life (McNeely et al 1979). The percentage of total ammonia which is un-ionized is determined by the pH and temperature. A worst possible case example for a stream draining agricultural lands (pH=8.5, temp.=25°C) could result in up to 15% of the total ammonia being present in the un-ionized form (G. Owen, Ont. Ministry of the Environment, Kingston, Ontario, personal communication). For humans, ammonia-nitrogen in drinking water should not exceed 0.5 mg/L (McNeely et al 1979). Natural waters generally contain concentrations of less than 0.1 mg/L total free ammonia.

Table 32. Quantities and characteristics of manures produced by livestock (kg/animal/day)

LIVESTOCK	TOTAL MANURE (wet weight)	BOD	SS	NITROGEN	P_2O_5	SODIUM
BULLS COWS (milk) COWS (beef)	40.9	0.66	0.89	0.15	0.06	0.01
STEERS (beef) HEIFERS (milk) HEIFERS (beef)	22.7	0.75	0.93	0.05	0.05	0.005
CALVES	11.4	0.16	0.24	0.04	0.01	0.005
PIGS (feeder)	4.5	0.17	0.15	0.03	0.02	0.003
SOWS	6.5	0.19	0.08	0.028	0.02	0.004
SHEEP (ewes)	5.4	0.15	0.10	0.02	0.01	0.001
SHEEP (lambs)	3.6	0.10	0.05	0.01	0.009	0.0005
HORSES & PONIES	25.	0.64	0.86	0.45	0.04	0.005
HENS (layers) CHICKENS (hatchery) TURKEYS (heavy)	0.14	0.011	0.006	0.002	0.0013	0.0001
HENS (pullets) TURKEYS (broiler)	0.073	0.006	0.005	0.0007	0.0004	0.0001
CHICKENS (broiler)	0.041	0.004	0.004	0.0015	0.0001	0.00005
TURKEYS (hatchery)	0.14	0.014	0.009	0.0021	0.0002	0.0002

Loehr 1974.

The organic components of manure are detrimental to aquatic life since their degradation requires high levels of oxygen, particularly during the summer months when elevated temperatures promote rapid bacterial decomposition. This results in oxygen depletion of the water, suffocation of fish and eventually a shift to anerobic decomposition. Methane and other gases are then produced.

Animal manure may also contain pathogenic organisms which are infectous to man. Salmonella, a common infectious bacteria transmitted by manure, can survive up to a year in liquid manure. The occurence of infections caused by field disposal is low. Contaminated water supplies however have the potential to infect many people and can result from improper storage or spreading manure too close to waterways. A less common but more serious bacterial infection transmitted by water contaminated by manure is leptospirosis. It can produce an infection through skin contact alone. Streams receiving runoff from pastures grazed by infected animals have been reported as a source of this infection (Hore and MacLean 1972).

Anthrax, tularemia, brucellosis, erysipelas, tuberculosis, tetanus and colibacellosis are other bacterial infections which can potentially be spread by manure. While some have a relatively short survival time outside their host, others such as anthrax are able to survive for several decades. Viral diseases may be transmitted by manure, and it is suspected that certain fungal and parasitic diseases may be carried in animal feces. Animals are capable of transmitting these infectious organisms even before they exhibit symptoms of the disease. It is important therefore, to minimize the risk of water contamination from all manure sources.

Manure entry into streams is a serious environmental hazard. It is a violation of the Ontario Water Resource Act (1967) and the Environmental Protection Act (1971) and it can result in the issuing of a control order requiring specific abatement measures. In extreme cases court action can be used to close an operation until proper corrective measures are completed. The Ontario Drainage Act (Anonymous 1975) also prohibits the entry of any polluting material, such as manure, into a municipal drain, with provisions for fines to be levied against offenders.

A review of the groundwater pollution problem by Robbins and Kriz (1969) showed that barnyards, feedlots and manure piles could produce elevated nitrate levels in groundwater. Under certain conditions it would be possible for groundwater pollution from other nutrients and organic and inorganic matter, although this problem has not been reported to date. Coote and Hore (1978) showed that groundwater nitrate contamination could occur under an unpaved feedlot. They also found that the nitrogen level declined more rapidly than would have been expected through dilution alone and it was felt that denitrification was playing a large part in this decrease. Nitrate-nitrogen levels varied greatly with distance from the manure source and a peak of nitrate-nitrogen was observed about 20 m from the feedlot. Wells, streams or tile drains at this distance would have a high probability of nitrate contamination.

4.2 Importance of Management Decisions

Manure handling systems should be designed to ensure maximum benefits from nutrient recovery and protection of surface and ground waters. Consideration must be given to: 1) the location of new animal facilities; 2) the location of manure storage areas; 3) the type of storage; and 4) the method of utilization or disposal. Manure and runoff water contaminated with manure should be kept away from all intermittent or perennially flowing watercourses.

Research during the PLUARG studies in the Ontario Great Lakes Basin found that it was not the size of the operation or the type of animals present that determined phosphorus export, but rather how storage and disposal were managed. A well-managed moderately-sized (<500 animals) feedlot was found to export a low level of nutrients and bacteria regardless of the type of buildings and density of housing, while a poorly managed operation could export a large amount of phosphorus generally proportional to the animal number and directly related to the animal type (Beak Consultants Ltd. 1977).

Coote and Hore (1978) also found that management was the key factor in controlling manure runoff from livestock facilities. Important considerations included type of storage and location, local soil conditions, topography and surrounding land use. Data from Wisconsin (Madison et al 1980) showed that unmanaged barnyards were the largest contributors of pollutant loads in dairy farming watersheds. Elevated nutrient and bacterial levels also resulted from direct access of livestock to streams. The location of tile lines relative to manure sources was another important factor in determining pollution transport to streams (Beak Consultants Ltd. 1977).

In another study a buffer strip 30 m wide cropped to sorghum-sudangrass and oats was placed around a feedlot on a 4% slope; runoff was reduced by 67 percent and transport of total solids by 79 percent (Young et al 1980). Total nitrogen and total phosphorus were reduced by an average of 84 and 83 percent respectively and ammonium nitrogen and phosphate phosphorus were similarly reduced. Bacterial coliform levels decreased as runoff passed through the vegetated buffer strip. On the other hand average concentration of nitrate-nitrogen in runoff increased because of leaching from the buffer strips.

The danger of water pollution from land applied manure can be avoided or minimized if proper procedures are followed. Factors which ensure manure application to land in an environmentally suitable fashion include: 1) suitable crops to receive manure; 2) knowledge of crop uptake requirments; 3) time and equipment available for application; and 4) soil testing to prevent nutrient imbalances from repeated manure applications. An ideal situation would be the immediate incorporation of manure with nutrient levels equivalent to crop requirements, applied at a time when crop uptake is high. This ensures maximum benefit to the farmer while minimizing the likelihood of water pollution.

Winter application of manure is an issue which as yet has not been resolved. Many scientists feel that if the work follows recommended procedures, it will not increase water pollution problems. Winter applications should be limited to areas which do not contribute snowmelt runoff directly to surface waters, since they produce higher nitrogen, phosphorus and potassium concentrations in the runoff than do spring and spring-fall applications (Phillips et al 1981). Manure spreading should always be done at a sufficient distance from waterways to allow pollutant concentrations to attenuate before runoff reaches open water.

Each situation is unique, as PLUARG stressed in their final report (IJC 1978). They felt that water pollution problems related to manure could be overcome by increased use of information provided through educational programs related to the design, construction and use of proper manure management systems rather than through legislated requirements.

The following practices indicate ways to reduce the pollution potential inherent in manure storage and disposal. There is, however, no single 'best' management practice for any given problem.

4.3 Specific Alternatives For Livestock Manure Management

4.3.1 Location of livestock facilities

The distance required for natural filtering of contaminants varies from site to site, but 122 m (400 ft) has been suggested for 'average' conditions. Sites with steep slopes and excessively permeable or impermeable soils require greater distances between the manure and water body (Coote and Hore 1978). Where present facilities are closer than this recommended distance, manure and runoff can be 1) contained or 2) re-routed to increase the distance traveled before contaminated runoff reaches an open water course. Careful placement of manure with a high percentage of bedding material ("solid manure") can produce a barrier to runoff of the semi-solid slurry. Improved river water quality resulted from the construction of a settling basin and the channelling of runoff through a terraced, vegetated buffer system between a large feedlot only 366 m from open water (Miller 1980). Sub-surface drains should not be located under or near feedlots or manure storage areas unless the drain ends or outlets to the soil surface 122 m (400 ft) or more from a water body.

4.3.2 Adequate manure storage facilities

A secure holding facility will be necessary to contain manure and runoff where there is insufficient distance to a water body and re-routing of runoff is not feasible. Excavated holding structures should be paved or lined to prevent percolation to the groundwater. Compaction of soil without an additional artificial lining is generally unsatisfactory because of crack formation when the structure is empty. These cracks can form direct conduits, carrying contaminants to the groundwater when the structure is refilled. Below-grade reinforced concrete tanks are

suitable for storage of liquid manure and will prevent groundwater pollution. Above-ground liquid storage systems and pipeline connections must be protected to prevent accidental leakage and/or breakage from freezing.

A minimum of 6 months storage capacity is recommended in the Ontario Agricultural Code of Practice (Anonymous 1976) but circumstances such as inflow of roof runoff or the possibility of limited field access for extended periods can increase storage requirements to 9 months or one year. In some Ontario situations, insufficient storage capacity has resulted in overflow, causing stream contamination and fish kills (C. Schenk, Ont. Ministry of the Environment, London, Ontario, personal communication).

The accumulation of a solid manure pack on feedlots is another method of temporary manure storage. Research in Nebraska indicated that despite very high nitrogen levels in the manure pack there was little pollution of groundwater. The depth of the manure pack above the soil surface apparently provided an effective barrier to downward water movement (Meikle et al 1970). Surface runoff, however, must be prevented or adequately treated.

4.3.3 Minimizing volume of liquids to be handled

Manure collection and handling systems should be designed to minimize the volume of waste. The design should include features which prevent rain and snow from contributing to the volume of material to be handled. Properly installed eavestroughs effectively direct water away from the barn or feedlot and diversions or grassed waterways can be used to advantage to route excess surface drainage away from the yard. Strategically placed windbreaks around buildings can be useful in reducing the amount of snow which drifts into a barnyard or feedlot. If it is not controlled, snowmelt runoff in the spring can contribute up to 30 percent of the annual feedlot runoff (Madden and Dornbush 1971).

Roofed "loafing" areas with eavestroughs will further help reduce the volume of manure to be handled. In areas with excessive precipitation, roof extensions on livestock barns and loafing areas keep manure drier and reduce the volume of liquids requiring treatment.

4.3.4 Land disposal and incorporation of manure

Land disposal and incorporation is presently the most economical means of manure disposal for the majority of farmers. Sites suitable for manure application should have low erosion potential, be situated away from streams or hillsides leading directly to waterways and should not be located in drainage pathways or grassed waterways.

Manure application rates for crop production are often estimated according to the nitrogen requirements of the crop. Crops best able to utilize nutrients from manure are corn, potatoes, and the hay and pasture mixtures dominated by grasses (Webber and Lane 1969). Excess manure applications however, can injure the crop and create a pollution problem for surface and ground water. The Ontario Agricultural Code of Practice recommends that manure be spread at the rate of one "animal unit" per hectare which is approximately equivalent to 169-191 kgs of nitrogen per hectare per year, (Anonymous 1976). The Agricultural Code of Practice definition of an animal unit is given in Table 33. Table 34 shows the maximum recommended rates of livestock manure application for land areas with different soil types. These were considered the rates at which manure could be applied without causing groundwater pollution or reduced crop yields. Manure should not, however, be applied just before a summer storm, or where site locations could result in runoff entering a stream. The value of manure incorporation for reducing nutrient losses in surface runoff was shown by Minshall et al (1970). Nutrient losses from summer manured plots with manure incorporation were less than from check plots receiving no manure.

Research in Wisconsin showed that up to 20 percent of the N, 13 percent of the P and 33 percent of the K nutrients from manure applied on frozen ground could be lost under conditions which maximized early spring runoff (Minshall et al 1970). However Robinson and Draper (1978) estimated that winter application of manure did not present a significant pollution problem to the Great Lakes. Much will depend on the conditions under which the spreading is done, the location of the site relative to waterways and the nature of the spring thaw.

Young and Mutchler (1976) found that nutrient concentrations in spring runoff were higher from manured plots compared with unmanured plots, but the actual losses varied greatly depending on the type of soil surface and time of application. Manure spread on frozen alfalfa resulted in up to 20 percent of the N and 16 percent of ortho-P being carried away in the spring runoff. Manure applications on plowed land however, reduced soil losses 100 percent and runoff up to 80 percent with no more than 3 percent of the N and 4 percent of the ortho-P being lost. The timing of manure applications with respect to snow cover also had an effect, as manure on top of snow cover was generally better at reducing soil, water and nutrient losses. Over-winter manure applications on fall plowed plots did not significantly increase the total nitrogen loss, which was generally less than the total annual nitrogen input from precipitation. Young and Holt (1977) found that nutrient losses from manured corn plots were less than from unmanured corn plots (averaged over a three year period), and were probably influenced by the 42 percent reduction in runoff and the 60 percent reduction in soil loss observed on the winter manured corn plots.

Further research may better define the value of winter manuring in Ontario as a soil and water conservation tool for reducing the annual pollution load. The amount of solids and nutrients in the manure, weather conditions and proximity to drainage courses are all factors which must be considered. Manure spreading on floodplains however,

TABLE 33. Animal units of manure production (in terms of nitrogen).*

Type of Livestock or Poultry	Annual Basis (365 Days)
1 dairy cow (plus calf)	1 animal unit
1 beef cow (plus calf)	1 animal unit
1 bull	1 animal unit
1 horse	1 animal unit
4 sheep (plus lambs)	1 animal unit
4 sows (plus litter to weaning)	1 animal unit
125 laying hens	1 animal unit
100 female mink (plus associated males & kits)	1 animal unit
	Market Basis (as marketed)
2 beef feeders (gain 180-495 kg)	1 animal unit
4 beef feeders (gain 180-338 kg)	1 animal unit
4 beef feeders (gain 338-495 kg)	1 animal unit
15 hogs (gain 18-90 kg)	1 animal unit
1000 broiler chickens or roasters (1.8-2.3 kg)	1 animal unit
300 turkey broilers (5-5.4 kg)	1 animal unit
150 heavy turkey hens (8.6-9 kg)	1 animal unit
100 heavy turkey toms (13.5-14.4 kg)	1 animal unit
40 veal calves (gain 40.5-135 kg)	1 animal unit
1000 pullets	1 animal unit

* Anonymous 1976

TABLE 34. Recommended maximum rate of livestock manure application per year.*

Manure Source	Minimum hectares	
	Loam to clay soil	Sandy soil
30-40 animal units	8 ha	12 ha
41-60 animal units	12 ha	18 ha
61-80 animal units	16 ha	24 ha
81-100 animal units	20 ha	30 ha
101-120 animal units	24 ha	36 ha
121-140 animal units	28 ha	42 ha
141-160 animal units	32 ha	48 ha
161-180 animal units	36 ha	54 ha
181-200 animal units	40 ha	60 ha
201-220 animal units	44 ha	66 ha
221-240 animal units	48 ha	72 ha
241-260 animal units	52 ha	78 ha
261-280 animal units	56 ha	84 ha
281-300 animal units	60 ha	90 ha
301-320 animal units	64 ha	96 ha
321-340 animal units	68 ha	102 ha
341-360 animal units	72 ha	108 ha
361-380 animal units	76 ha	114 ha
381-400 animal units	80 ha	120 ha

* Anonymous 1976

is not recommended. Winter disposal of manure, if necessary, should not be done near a water course. Ideal sites are flat or gently sloping land without direct runoff to open water. Application rates should not be excessive so as to reduce the probability of spring snowmelt runoff washing the manure into a drainage system. Adherance to these precautions should help reduce potential pollution hazards.

Liquid manure irrigation requires special precautions to ensure that the manure does not reach open water or result in excessive leaching to groundwater. Systems require careful maintainance to prevent leakage or broken pipelines. A vegetated area should be maintained between the disposal site and nearest water course to reduce the possibility of stream contamination. Subsoil injection reduces the possibility of runoff losses while also reducing odour problems. Research by Patni and Hore (1978) showed that heavy applications of liquid manure (approximating 500 kg N/ha/yr) split into spring and fall applications did not impair the quality of stream and subsurface water where low nitrogen application rates had been used in the past and the manure was incorporated into the soil. Most losses occurred with the spring runoff and tile flow. Later work (Patni et al 1981) showed elevated nitrate and ammonia concentrations in groundwater after 3 or 4 heavy liquid manure application on a well-drained sandy soil.

4.3.5 Management of livestock on grass

Nutrient contamination of streams from livestock was a source of contamination which was not quantified in the PLUARG studies. The type and number of animals, size of field, soil type, topography, distance to stream and intervening vegetation all affect contaminant transport to a water course. Table 35 illustrates the different characteristics of pasture land runoff from different animals and animal densities. Research data have indicated that animal access to streams resulted in larger additions of total nitrogen, phosphorus and organic carbon per animal than did the spreading of manure adjacent to a stream (Howells et al 1971). Other studies have indicated that total coliform, fecal coliform and fecal streptococci are significantly higher in storm runoff from grazed areas than from non-grazed areas. They were also higher in streams accessible to cattle (Loehr 1974; Beak Consultants Ltd. 1977). Fencing of streams with provision for alternate watering facilities will reduce nutrient pollution (Robinson and Draper 1978) and prevent bank erosion from cattle trampling.

4.4 Summary

Table 36 summarizes manure management practices suitable for protecting water quality. The production, storage and use of manure in the Ontario Great Lakes Basin is not a serious threat to Great Lakes water quality at present. The continued intensification of livestock operations could, however, increase the potential for

Table 35. Runoff characteristics of pasture land in North Carolina.*

LAND USAGE	AVERAGE CONSTITUENT (g/ha/day)[1] BOD	COD	TOC	NO_3-N	TOTAL N	TOTAL P
250 Hog drylot, row crops, wood, grassland	35	--	97	1.7	7.7	3.5
Pasture for 50-100 dairy cows plus corn	44	750	150	4.0	38	25
Pasture for 160 cows on 15 acres	3450	10,700	3,750	47	400	130
35 Beef cows on 15 acres of pasture	46	720	150	—	5.8	1.8

[1] 1.0 g/ha/day = 8.9×10^{-4} lb/ac/day

* adapted from Howells et al 1971, as reported by Raymond Loehr 1974.

serious localized water quality problems which could affect both man and the aquatic ecosystem. Management has been identified as the most important factor in determining the potential pollution hazard of an operation. Improved understanding of the possible hazards and increased efforts to manage manure properly are required. Practices such as adequate on site-manure storage, buffer zones, properly timed applications away from drainage areas, incorporation of field applied manure and exclusion of animals from streams could reduce or eliminate the needless incidences of water pollution of manure. Management for pollution control does not necessarily present an economic constraint on an operation and it has been shown that pollution control measures can be successful combined with an economically viable farm operation.

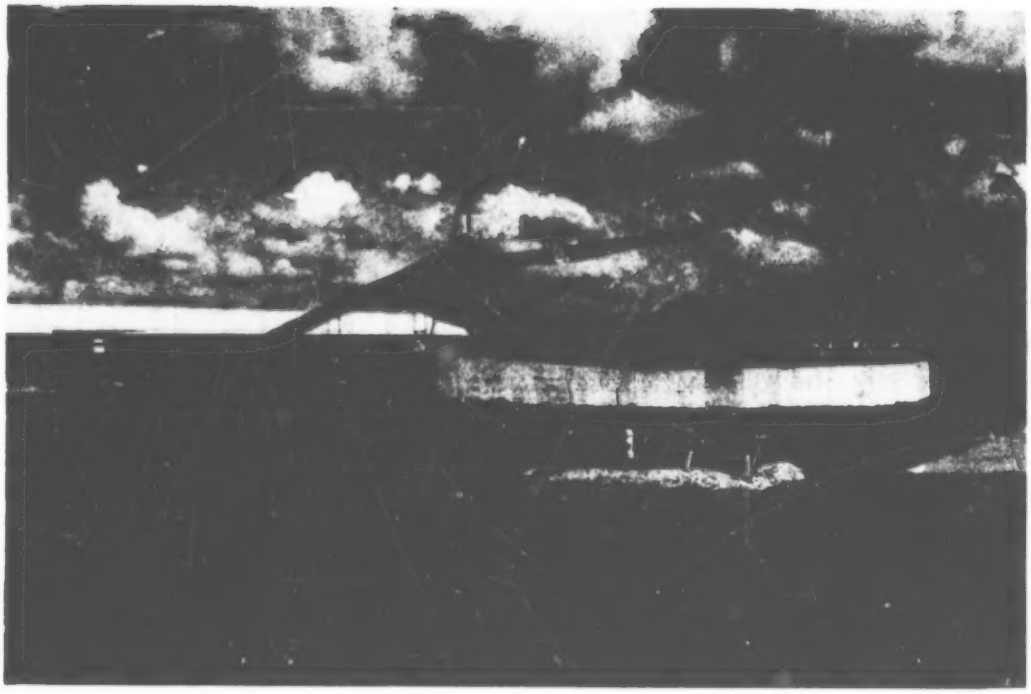
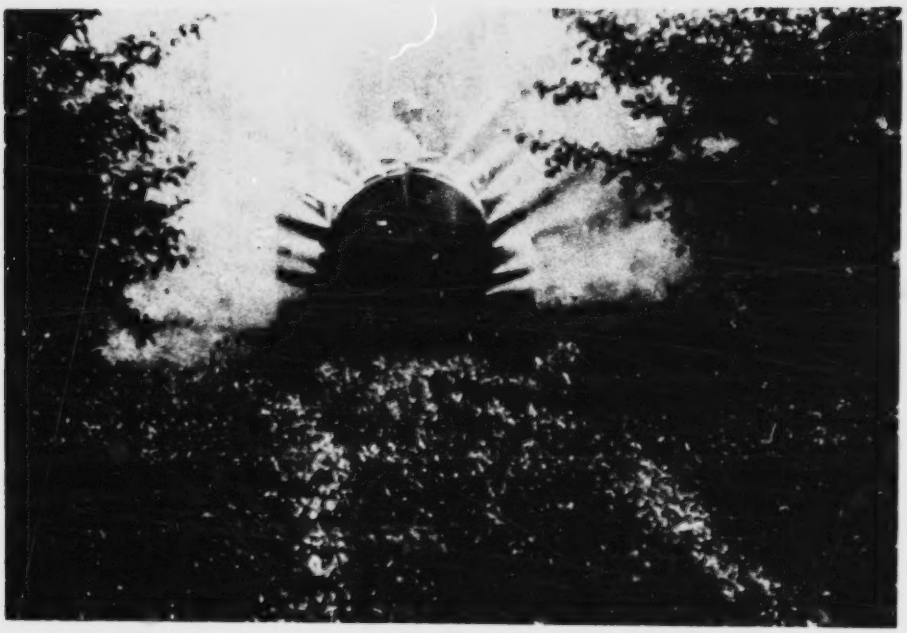


Table 36. SUMMARY OF LIVESTOCK MANURE MANAGEMENT PRACTICES

Practice	Where applicable	Advantages	Disadvantages
1. Location of livestock facilities	-when rebuilding or establishing new facilities -especially important when operation close to open water or water recharge areas	-allows attenuation of contaminants before they reach streams and groundwater -cost of future water pollution control reduced by proper site selection if insufficient storage	-may be costly, depending on structural alterations or topography -land requirements for retaining or filtering runoff
2. Adequate manure storage facilities	-operations with high density animal units sited on permeable soil and/or close to open water -all livestock operations directly adjacent to water bodies -livestock operations where year round disposal not possible	-protects groundwater and surface streams from high nutrient inputs -reduces likelihood of overflow or of insufficient storage during an exceptionally wet year -allows for efficient use of manure nutrients on crop land reduces pressure to dispose of manure during unfavourable conditions	-may be costly and provide little immediate financial return
3. Minimizing volume of liquids to be handled	-any outside livestock or manure storage area -important where precipitation high and snowfall accumulation can be significant	-diverting roof runoff and overland runoff away from manure reduces volume of contaminated liquid to be disposed of later -reduces size of storage area required -diversion of roof runoff is relatively inexpensive	-topography may make runoff diversion expensive -exclusion of precipitation itself from storage area by roofing is costly
4. Land disposal and incorporation of manure	-operations producing and/or using manure -best with conventional or minimum till -important on sloping fields -avoidance of drainage networks important where winter disposal necessary	-reduces runoff, nutrients and particulate losses -reduces odour and potential pathogen problems -reduces likelihood of localized surface and groundwater contamination	-timeliness may be a problem -liquid injection only method compatable with no-till -increased cost of larger storage area and/or labour and equipment to optimize use

		-can produce good yields while reducing overall fertilizer costs -improves soil structure by adding nutrients and organic matter -incorporation of manure increases efficient use of nutrients -reduces storage necessary -may reduce erosion	-availability of sufficient land with intensive confined animal operations on small acreages -most efficient use of manure requires a well managed cropping program -cost of transporting to land disposal areas
5. Management of livestock on grass	-livestock pastures with stream access	-fencing and buffer strips reduce nutrient loads and possibility of pathogen contamination of water	-increased cost of fencing -removes some land from grazing -cost of providing alternate animal watering facilities



5. PESTICIDES

5.1 Introduction

Pesticides provide benefits to agriculture in the form of increased yields and improved quality of produce. However they can also cause environmental problems such as fish kills, reproductive failures in birds and illness and genetic alterations in man and animals. Table 37 illustrates some pesticides and the properties which effect their likelihood of causing environmental hazards. Because agriculture is a major user of pesticides agricultural applications have often been cited as a primary cause of environmental problems. At present most registered pesticides are not toxic to mammals at normal use levels. The effect, however, of long term, low-level exposure is not well understood. They may have mutagenic, carcinogenic or teratogenic effects which will only show up in later generations.

The controversy over pesticides first centered around the organochlorine insecticides, and DDT in particular. It was not toxic to mammals but did accumulate in the environment and, being highly lipid soluble, it was concentrated in body fat and passed on to each successive level of the food chain. Thus DDT underwent a biomagnification, with levels in animal tissues several orders greater than those in the surrounding water and sediments. Furthermore, it remained in the environment for extended periods. DDT use was restricted in 1970 in Ontario and banned in 1972, but residues are still found in water, sediment, and fish tissue samples. DDT has been shown to cause reproductive problems in salmon (Locke and Havey 1972). It has also resulted in declines in the populations of some fish-eating birds by creating an imbalance in calcium metabolism leading to thinner egg shells and a higher loss of eggs in the nest through breakage (Nicholson and Hill 1970). Other behavioural and physiological disorders have also been attributed to DDT (Brown 1978). The effect of DDT and its metabolites on man has not been clearly documented, but its accumulation in the environment and effect on fish and avian reproduction was sufficient to cause considerable concern.

The organochlorine compounds have generally been replaced by organophosporus and carbamate insecticides. Unfortunately little information is available on the effect of these in the aquatic environment. Harris and Miles (1975) reported the presence of organophosphate insecticide residues in the Bradford Marsh. The PLUARG studies undertook an extensive monitering program in selected agricultural watersheds in the Ontario Great Lakes Basin (Frank et al 1978), and results indicated that the newer insecticides appeared to be non-persistant and were rarely found as contaminants in stream water. In recent years some insect resistance to these new compounds has been noted, however, leading to higher levels of insecticide usage and a build-up of residues in some organic soils.

Herbicides are used to control unwanted vegetation not only in agriculture but also on industrial and home properties, along utility rights of way, in forests and in recreational areas. Herbicides are used more widely than insecticides in Ontario and a survey carried

Table 37. Relevant environmental properties of some common agricultural pesticides used in Ontario [1]

Common name	Trade name	Pesticide class	Formulation[2]	Predominate mode of transport[3]	Solubility[4] mg/l	Approximate persistance in soil[5]	Toxicity[6] Rat acute oral LD_{50} mg/kg	Toxicity[6] Fish[7] LC_{50} mg/L
Alachlor	Lasso	anilide herbicide	EC GR	SW	242	P_1	1200	2.3
Amitrole	Amizol	triazine herbicide	SP SN	W	sol[a]	P_1	1100-24600	$\geq$350
Atrazine	AAtrex	triazine herbicide	SN SG WP SU	SW	33	$(P_1 \rightarrow P_4)+$	1859-3080	12.6
Cyanazine	Bladex	triazine herbicide	WP SU	SW	171	$(P_1 \rightarrow P_4)+$[b]	182-334	4.9
Diclofop-methyl	Hoegrass	phonexy herbicide	EC		0.3 (22°C)	P_1	557-580	toxic
Glyphosate	Roundup	organophosphate herbicide	SN	S	sol	P_1, P_2	4320	low toxicity
Metalachlor	Dual	acetanilde herbicide	EC		530 (20°)	P_1	2780	15
Metribuzin	Sencor Lexone	triazine herbicide	WP SU SG	W	1,220 (20°C)	P_1, P_2	200-2345	7100
Paraquat	Gramoxone	bypyridinyl herbicide	SN	S	sol	$(P_1 \rightarrow P_4)++$	157-207	400[c]
Trifluralin	Treflan	dinitroaniline herbicide		S	0.05	P_1, P_2, P_3	3700-10,000	0.1[c]
2, 4-D (amine)		phenoxy herbicide	Gr	W	sol	P_1	370	715[d]
2, 4-D (ester)		phenoxy herbicide	EC SN	S	10-500[b]	P_1	375-875	4.5[d]
MCPB (salts)	Tropotox	phenoxy herbicide	SN		44 (22-23°C)		680	
Carbaryl	Sevin	carbamate insecticide	WP	SW	40	P_1 -	500-850	1.0
Carbofuran	Furadan	carbamate insecticide	F	W	700	P_1, P_2[b]	8-14	0.08-0.24

Diazinon	Diazinon	organophosphate insecticide	WP	SW	40	P_1	300-850	0.030
Fensulfothion	Dasanit	organophosphorus insecticide	Gr	SW	1540	$(P_1->P_4)+$	4.72-10.5	0.15[c]
Malathion	Malathion	organophosphorus insecticide	WP EC	W	145 (22-23°C)	P_1	480-5800	0.019
Methoxychlor		organochlorine insecticide	EC WP	S	0.1-0.25	$(P_1->P_4)+$	5000-6000	0.009
Phorate	Thimet	organophosphorus insecticide	Gr	SW	80-85	P_1	1-3.7	0.0055

1. References: Stewart et al 1976; Wauchope 1978; Worthing 1979.
2. Common formulation: EC=emulsifiable concentrate; Fl=flowable; Gr=granular; SG=soluble granules; Sn=solution; SP=soluble powder; Su=suspension (flowable); WP=wettable powder.
3. Primary mode of pesticide transport in runoff from treated fields, S denotes sediment bound, W denotes those moved with the water, and SW indicates that an appreciable proportion will move with both sediment and water.
4. Solubility of pure (unformulated) material in water near 25°C, unless otherwise indicated.
5. Field losses are highly variable, depending on formulation, soil type, weather and other factors, and can vary by several orders of magnitude. Possible loss periods within a crop year are: P_1=April-June, P_2=July-Sept., P_3=Oct.-Dec., P_4=Jan.-Mar. Presistant pesticides exhibit field losses beyond one cropping year (i.e. $(P_1-P_4)+$).
6. Expressed as lethal dose (LD) or lethal concentration (LC) to 50 percent of the test animals. Range in values due to testing of different formulations.
7. 48- or 96- hour LC_{50} for bluegills or rainbrow trout, unless otherwise stated.

a Solubility > 10 percent weight/volume.
b Assumed from properties of similar compounds.
c 24-hour LC_{50}.
d For Japanese killifish.

out in 1978 (Roller 1979) showed that herbicides accounted for more than 75 percent of the pesticides used on field crops. Herbicides generally have lower mammalian and avian toxicities than insecticides and they usually degrade to biologically inactive forms within a few weeks in the environment. A few, such as simazine, atrazine and diuron, can persist longer but there has been no evidence of environmentally related problems (Frank et al 1978; Millard et al 1979). Fungicides, acaricides (miticides), bactericides and nematicides are not used as widely as insecticides and herbicides and few data are available on residue effects. Work by Frank et al (1978) and Millard et al (1979) found little evidence of problems in aquatic environments from pesticides presently used in Ontario.

5.2 Importance of Management Decisions

Pesticide use, especially of herbicides, has risen dramatically over the past ten years. In 1978, 5803 metric tons of pesticides were used on Ontario field crops. Herbicides accounted for 78 percent of this figure (Roller 1979). Pollution from the entry of a pesticide or its degradation products into the aquatic environment can be caused by: 1) direct application, or spills; 2) runoff or percolation of soluble materials; 3) transport as an aqueous suspension, and 4) erosion of material bound to sediment. The fate of a particular pesticide after application is determined by a variety of factors, relating to its use, persistence and movement.

Total pesticide losses in runoff waters and associated sediments are less than 0.5% of the amounts applied for the majority of commercial pesticides. Heavy rainfall within 2 weeks of application can, however, greatly increase percentage losses of all pesticides. For wettable powder herbicide formulation applied to the soil surface, losses in runoff of up to 50% can occur as the powder is easily transported in suspension or bound to sediment (Wauchope 1978). Some insoluble pesticides which are foliar applied as emulsions have exhibited losses of about 1 percent or less (Wauchope 1978). Such losses are usually caused by transport in suspension rather than in association with sediment movement (Hall 1974). Higher losses can be found with paraquat and the arsenicals which are easily immobilized and remain at or near the soil surface where they are susceptible to runoff water and sediment transport. If a storm occurs soon after application, losses of non-incorporated pesticides are increased approximately 3 to 6 times the average (Smith et al 1978, Triplett et al 1978, Wauchope 1978).

Groundwater pollution from pesticides leaching through the soil is not considered a significant hazard, although low-level pesticide contamination has been reported (Stewart et al 1976). Movement of even relatively mobile chemicals to ground water at depth would require a great deal of downward water movement, a concentrated pesticide source (i.e. spill) (Frank et al 1979), or very permeable soils (Anonymous 1980b).

Pesticide spills from human carelessness cause local surface water quality problems and were the suspected source for the occasional presence of some materials in stream samples during the PLUARG studies (Frank et al 1978). This type of contamination can be prevented by proper use of pesticides, care in mixing and emptying sprayers and proper disposal of empty containers and left-over spray. Spray drift along a water course or near a well can also lead to environmental problems, particularly with aerial spraying.

Methods are under investigation to dissipate the compounds once they enter the environmental chain. Such methods include use of aquatic plants as traps, inocula of microorganisms to enhance degradation, direct chemical inactivation by addition of a reactant, use of additives to control the metabolic degradation of herbicides within plant tissues and use of new absorptive media or ion exchange resins to remove residues from water (Foy and Bingham 1969).

The following practices are those which may be used by an individual farmer to ensure that pesticide use on his farm does not result in environmental quality problems.

5.3 Specific Alternatives For Pesticide Management

5.3.1 Reduction of transport losses

Pesticides which are removed from fields attached to soil particles can be controlled through soil conservation practices. However reduction in sediment may not result in a proportional drop in pesticide yields because most transport of incompletely absorbed herbicides occurs in solution (Smith et al 1978; Baker et al 1976). Wauchope (1978) found that, in general, erosion control practices effectively controlled pesticide losses for those pesticides with solubilities of 1 ppm or less or ionic pesticides with strong clay binding capabilities (i.e., paraquat and the arsenicals) but had little effect on other pesticides.

The control of the majority of pesticide losses will involve runoff reducing measures (Trichell et al 1968). Ritter et al (1974) showed that atrazine losses were proportional to runoff volumes from corn fields. Zero-tillage with adequate residue cover reduced herbicide losses of atrazine and simizine to less than those with conventional tillage (Triplett et al 1978). The reductions were attributed to the mulch cover increasing infiltration and slowing overland flow, thereby decreasing total runoff and associated herbicide losses.

Sodded areas and grassed waterways reduce chemical loss through increased infiltration, degradation, reduced sediment transport (by entrappment, interception and absorption of the chemicals by the nontreated vegetation), or a combination of these. Trichell et al (1968) found that picloram runoff losses from plots with an 8 percent slope were reduced 42 percent after passing over untreated sod. Evans and Duseja (1973) reported that a few hundred meters of untreated sod were sufficient to reduce the runoff concentration below the detection limits of the herbicides under study.

Research with 2,4-D showed losses from treated corn plots could be reduced by approximately 70 percent through the use of a grassed waterway (Asmussen et al 1977). Trifluralin concentration in runoff decreased by 96 percent following dry conditions and 86 percent following wet conditions on passage through a grassed waterway (Rohde et al 1980).

Increased infiltration could, however, effect the mode of certain pesticide losses, such as the triazine group. Von Stryk and Bolton (1977) found that atrazine losses to tile lines were predominantly related to the amount of water moving through the soil profile, and were about 0.8 percent of the amount applied. Quebec research also indicated that triazine herbicide residues in tile effluent were related to the amount of water moving through the soil to the tile lines. About 0.15 percent of the atrazine, cyprazine, cyanazine and metribizin that were applied appeared in the tile effluent, either unchanged or as degradation products (Muir and Baker 1977). The effects of reducing pesticide transport in runoff water on the pesticide content of ground water and tile effluent has not been determined but will require close monitering to ensure that serious water quality degradation does not occur.

5.3.2 Reduction in use

(a) Use of integrated control measures

Integrated pest management, a combination of chemical, biological, cultural and/or mechanical control measures, reduces over-dependance on any one method and as a result, pesticide use can often be substantially reduced. These programs do not require large capital expenditures yet can save time, lower costs and reduce the likelihood of surface and/or groundwater contamination.

Partial control of the cereal leaf beetle and the alfalfa beetle has been achieved through the release of parasites. Research is proceeding towards similar non-chemical control of the onion maggot and coddling moth.

Monitoring of pest levels to eliminate pesticide use below certain infestation levels is another form of integrated control. This allows some forms of natural control to occur and reduces the amount of pesticide required (Hanson 1972). A program of stragetic spraying, i.e. spraying only at critical pest population levels, is being developed for apples in an effort to lower overall insecticide use. It could result in a 30-40 percent reduction. A similar approach has been used to develop a pest management program for peaches in Ontario. The standard preventive program recommends 20 different spay chemicals in 10 to 15 different applications. The "minimum" program uses 4 sprays to control the Oriental fruit moth, with 1 to 3 additional sprays depending on the occurance of secondary pests.

Close monitoring of European red mite numbers determine the necessity for spray applications (Prec et al 1980). Integrated programs have the potential of being one of the most effective ways of reducing the quantities of pesticides lost from crop land (Haith and Loehr 1979).

(b) Crop rotations

Rotations help prevent the buildup of insect populations by breaking the life cycle of certain insects which require a specific host. This was demonstrated in Illinois with statistics showing that almost 70 percent of the continuous corn fields were treated with soil insecticides in 1972, while only 42 percent of the fields in first-year corn were treated (Stewart et al 1975). Rotations are a recommended practice to help control northern corn root worm in Ontario. Organochlorine insecticide runoff losses from potato-oats-sod rotation plots were consistantly significantly lower than from a continuous potato plot (Epstein and Grant 1968). It was felt that the increased organic matter content present under rotation cropping helped to bind the pesticides and prevented their loss in runoff in all years of the rotation.

Rotations are also useful for weed control. For example quackgrass is virtually impossible to control in small grains but can be controlled in corn, while milkweed is more easily controlled with a small grains-corn rotation than with continuous corn.

The use of crop rotations to help suppress infestations of insects, weeds, and also plant diseases, means less pesticide will be used in the long term. The likelihood of residue buildup and pest resistance is decreased thereby reducing the possibility of crop, soil and water contamination.

(c) Resistant crop varieties

Crop varieties resistant to attack by disease or insects, for example hybrid corn varieties resistant to first generation corn borers, should be used whenever possible (Stewart et al 1975). Complete control is unlikely and supplemental chemicals will be required in many cases, but fewer treatments are generally necessary and overall pesticide use is reduced. Development of crop lines with improved levels of multiple pest resistance may also provide some adaptability and protection for future disease-risk situations, reducing the need for pesticide use (Hanson 1972).

(d) Use of alternate pesticides

Species resistance to a given pesticide sometimes necessitates increased application levels. This practice should be avoided whenever possible because of the increased risk of water contamination from chemical losses. An alternative solution is to change the pesticide with sufficient frequency that the target species does not develop

resistance. A change in pesticides will also prevent a build up of residues of any one compound and reduce the likelihood of water pollution. If a range of pesticides is available, those which are environmentally safest should be used. They will have a low toxicity, not persist and not accumulate through food chains.

The formulation of a pesticide can affect the amount of pesticide lost from a field (Wauchope 1978). Consideration should be given to the solubility of the chemical and its chief mode of transport since this determines whether losses are most likely from an erosion prone or a runoff producing area. It will also indicate which management practices are best suited to reducing such losses.

Environmental hazards can further be reduced if a pesticide is chosen with consideration for its environmental interactions. Some pesticide formulations are more hazardous than others because of the application method required, their principal mode of transport or the addition of solvents, additives or dilutents which may be more toxic to aquatic organisms that the active ingredient.

(e) Use of improved technology

Reductions in pesticide use and losses can also be achieved through improved application efficiency. New sprayers and spray techniques which require less spray and are more efficient are being developed. One involves the use of a large absorbant roller (or wick) which is soaked with a herbicide and comes in contact with any weeds which rise above the crop canopy. Another system employs two vertically opposing rows of nozzles, each with a backdrop and collection trough for collecting the spray not intercepted by the weeds. The spray is then recycled through the spray nozzles. An aircushion spray boom has also been developed which can markedly decrease spray drift, and prototype testing has suggested that substantial reductions in pesticide use may be possible. Other possibilities being investigated to improve spray efficiency and deposition include electrostatically charged sprays and optimized spray droplet size.

Foams, gels and polymer-encapsulated slow release formulations are being investigated to reduce drift, minimize pesticide movement in the environment and reduce the number of applications required. Reduction of pesticide volatilization from plant and soil surfaces (Foy and Bingham 1969), as well as precision placement of pesticides by devices such as subsurface sweep applicators (Reid and Peacock 1973) are also being studied.

(f) Optimizing planting dates

Certain crops are more susceptible to pest infestations when not planted during the optimum period. For example, early planting of barley helps avoid serious outbreaks of disease caused by the Bipolaris fungi i.e. spot blotch, seedling blight, root rot and head blight. Early seeding is also an advantage during years when there is an abundance of aphids which carry the barley yellow dwarf or oat red leaf virus. Pesticide needs can be reduced or eliminated by adherence to recommended optimum planting dates.

5.3.3 Use of proper handling procedures

PLUARG data (Frank et al 1978) showed that atrazine losses to water were about 1 percent of that applied annually, with 20 percent of that loss directly related to spills and careless handling during the spray season. 2,4-D residues in streams were directly related to spray operations around streams in 90 percent of the cases. The presence of other herbicides in streams was rare but could be associated with careless use around open waterways. Strict adherence to recommended storage, handling, application and disposal procedures as outlined in the Pesticide Safety Handbook (Anonymous 1979b), and the Guide to Chemical Weed Control (Anonymous 1981c) can eliminate many of the localized water quality problems caused by pesticides.

Pesticides should only be used when they are required to prevent economic losses. A reduction in volume of pesticides applied at field level will decrease the likelihood of runoff losses degrading water quality even if percentage losses are the same. This can be accomplished by employing more efficient equipment, such as the recirculating or wick applicators.

5.4 Summary

Pesticide management practices conducive to good water quality are summarized in Table 38. Pesticide contamination of water is rare under even the most favourable transport conditions, in spite of their widespread application. In Ontario only atrazine, the most widely applied herbicide, was regularly found (present in 80.2 percent of the water samples) in eleven agricultural watersheds over a two year period. It was not, however, considered to be an environmental hazard. The highest level recorded did not exceed either the IJC maximum proposed concentration standard, or the toxic level for local species (Frank et al 1978).

Most pesticides presently in use persist for only short periods. For the majority of commercial pesticides total losses do not exceed 0.5 percent of the amounts applied. However severe rainfall conditions within 1-2 weeks of application or human carelessness can increase these losses.

Continued pesticide use within the Great Lakes Basin is not seen as a major threat to water quality, however recommended procedures, as summarized in Table 38 should be followed at all times to avoid the possibility of localized surface or groundwater contamination.

Table 38. SUMMARY OF PESTICIDE MANAGEMENT PRACTICES

Practice	Where applicable	Advantages	Disadvantages
1. Reduction of transport losses	-all land where pesticides applied -area between open waterway and treated land	-reduced pesticide loss associated with sediment phase of runoff -increased infiltration reduces runoff, lowers pesticide loss associated with water phase of runoff -increased cost effectiveness of pesticides retained on land	-cost of installation and maintenance -some practices may result in lowered farm income (i.e. rotations) -some land removed from production -may limit use of atrazine -may increase downward movements of pesticides in soil profile
2. Reduction in use			
(a) Integrated control	-all farms -tillage system may eliminate some options	-reduces need for pesticide applications -better, more cost effective control -most likely to have significant effect on pesticide amounts entering environment	-not available for all pests, or in all areas -mechanical cultivation not compatible with minimum or no-till -yield reductions possible if all pesticide use eliminated
(b) Crop rotations	-any farm -more acceptable where market exists for all crops	-prevents build-up of pest infestations -helps reduce risk of resistance developing in target organism -decreases overall pesticide requirements -reduces risk of residue build up in field of any one pesticide	-requires market for all crops -increased equipment requirements
(c) Resistant crop varieties	-all farms -especially important in vegetables, some cereals	-reduces need for pesticide use -decreases production costs	-many cases where appropriate resistant variety not yet available -only resistant to present pest, not to new genotypes of same pest, or new pest

	(d) Alternate pesticides	-whenever a safer, economically effective pesticide exists	-helps prevent build-up of resistance in target species -reduces amount of any one pesticide entering environment -safer for other non-target organisms	-increases management responsibilities to ensure substitute provides adequate pest control
	(e) Use of improved technology	-increased costs may limit certain improved procedures to large farms or custom operators	-reduces unnecessary use and over application -increase cost effectiveness if pesticide is not wasted -improved control -reduces pollution potential if less pesticide in fields, decreases risk of injury to non-target organism	-increased time required to plan pesticide control program -time required to monitor fields for infestations and spray at optimum period -may require capital outlay for new sprayers -weather conditions can still result in field losses -unavailability of suitable formulations
	(f) Optimizing planting dates	-effectiveness limited to certain crops (ie: cereal grains). -may only be useful some year	-reduces infestations of some diseases	-may not be possible due to weather and/or labour and machinery constraints
3.	Use of proper handling procedures	-all pesticide users	-prevents unnecessary contamination from spills and spray drift -safe disposal of containers protects man and environment	-increased time required to familiarize self with proper procedures -increased time to do job properly and safely

6. MISCELLANEOUS CONCERNS

6.1 Sewage Sludge

The problems associated with the use of sewage sludge are very similar to those encountered with manure, with the additional problems presented by industrial contaminants (e.g. metals, organics).

Disposal of sewage sludge on agricultural land, an attractive proposition for urban communities, is a relatively inexpensive method of disposal since it uses the natural capacity of soil to accept and attenuate pollutants. At the same time sludge applications benefit the soil, since they contain up to 50 percent organic matter, contribute nutrients and improve soil physical properties. However there are risks involved. A phosphorus soil test is necessary, as sewage sludge should not be used on soils where the plant-available phosphorus of the top 15 cm is 60 ppm or greater. Sewage sludge should not be used on organic soils regardless of the soil phosphorus test (Anonymous 1978). Applications which provide more nitrogen than can be used by the crop can result in nitrate leaching to groundwater and increased surface runoff losses. Many municipal sludges also contain heavy metals and other potentially dangerous components, both biological (i.e. bacteria, viruses, parasites) and chemical (e.g. organics, such as insecticides, herbicides, polychlorinated biphenyls (PCB's) and other toxic materials). These can: 1) accumulate in the soil (ultimately proving toxic to plants, animals or humans); 2) be transported off fields with sediments and runoff waters; or 3) move downwards into ground waters.

The composition of some Ontario municipal sludges is shown in Table 39. The heavy metal content of sludge is highly variable, but any increase of such metals in the soil will likely increase heavy metal loadings to the Great Lakes; heavy metals can enter water associated with particulate matter or as the soluble form in leachates or runoff. At present unit area loads of heavy metals to the Great Lakes from untreated agricultural land are several orders of magnitude lower than those being added from general urban land use (IJC 1978). Atmospheric sources appear more important since atmospheric fallout added 5 to 16 times more lead, 4 to 8 times more zinc and 1 to 8 times more copper to the land than was contributed to streams by agricultural land (Coote et al 1978). Sewage sludge has been a major source responsible for the increase of trace elements in agricultural soil in the past. Cadmium is the heavy metal of greatest concern to human health (Pahren et al 1979). The cadmium content of sludge along with the levels of eleven other metals determine sludge suitability for application to agricultural land in Ontario. Ammonia plus nitrate-nitrogen levels are also considered in the suitability criteria. Table 40 illustrates guidelines for determining the suitability of a sludge for land application. Adherence to guidelines such as these will help reduce further contamination of agricultural lands by toxic metals, while runoff and sediment control measures will prevent the movement of metals currently in the soil to the Great Lakes drainage system.

Table 39. Characteristics of sludges produced by some Ontario waste treatment plants. *

Characteristic	Secondary Treatment Plants								
	Anaerobically Digested Sludge+			Aerobically Digested or Waste Activated Sludge++			Anaerobically and Aerobically Digested Sludges+++		
	Range	Mean	Standard Deviation $\pm_{\sigma}$	Range	Mean	Standard Deviation $\pm_{\sigma}$	Range mg/1	Mean mg/1	Standard Deviation ± mg/1
Total Solids (TS%)	2.0-12	4.1	1.8	2.2-4.5	2.75	0.95			
Volitile Solids (VS%)	36-70	51	8.5	41-96	55.8	9.9			
Ammonia Nitrogen (N mg/1)	250-1200	628	245	20-180	110	24.8			
Total Kieldahl Nitrogen (N mg/1)	1600-3000	2114	495	650-2300	1358	576			
Total Phosphorus (P mg/1)	390-2900	975	603	440-1200	730	303			
Zinc							4-225	55.5	57.4
Copper							7-148	34.8	30.2
Nickel							0.26-16.8	6.5	14.9
Chromium							2-430	41.6	51.7
Lead							3.7-60	21.8	25.1
Cadmium							0.1-8.7	1.4	2.0
Cobalt							0.3-3.6	0.8	0.8

\+ No. of plants = 25
++ No. of plants = 8
+++ No. of plants = 30

* Schmidtke 1978.

Table 40. Metal criteria for land application of sewage sludge. *

Metal	Mean metal content of uncontaminated Ontario Soils (ppm)	Maximum recommended metal content in soil (ppm)	Maximum recommended metal addition to soil (kg/ha) (in 50 year period)	STAGE I[a]		STAGE II[b]
				Minimum ammonium plus nitrate nitrogen[c] (NH_4^+-N plus NO_3^--N) to metal ratios required in sewage sludge	Number of sewage sludge applications to give maximum recommended metal content in soil (Col. 3)[d]	Ammonium plus nitrate nitrogen[a] (NH_4^+-N plus NO_3^--N) to metal ratios required to give maximum recommended metal content in soil (Col. 3) in 50 applications[b]
Arsenic	6.5	13	15	100	10	500
Cadmium	0.7	1.4	1.6	500	5	5000
Cobalt	4.5	18.0	30	50	10	250
Chromium	14.0	112	220	6	10	30
Copper	25.0	100	168	10	10	50
Mercury	0.08	0.5	0.9	1500	10	7500
Molybdenum	1.7	3.4	3.8	180	5	1800
Nickel	16.0	32	36	40	10	200
Lead	14.0	56	94	15	10	75
Selenium	0.4	1.6	2.7	500	10	2500
Zinc	54.0	2.6	363	4	10	20

[a] Interim criteria for use with currently produced sludges. Maximum number of applications limited to 10 (Col. 6).

[b] Future criteria for use with sludges with substantially reduced metal contents (either by metal removal at source, or extraction from sludges at treatment plants). This will allow long term use of sewage sludges on land.

[c] Measured as nitrogen.

[d] Based on 135 kg. ammonium plus nitrate nitrogen per application and sewage sludge having minimum ratios. Number of applications for cobalt and copper are rounded off to 10.

* Anonymous 1978.

Application of recommended sludges must also follow certain criteria to safeguard surface and groundwater quality. The site must not drain into open water courses and the separation distance required to meet this condition will be determined by slope, time of year (weather conditions) rate of sludge application, water content of sludge, existing vegetation and permeability of the soil (Council of Agricultural Science and Technology 1976). Sludge application must not precede periods of maximum surface runoff or be done when infiltration is restricted. Spreading on top of snow when there is little or no frost in the ground however, is considered relatively safe from runoff losses. Winter spreading on flat fields (0 to 3 percent sustained slope) at least 360 meters from a watercourse, where the risk of runoff or flooding is minimal, is acceptable (Anonymous 1978). Depth to ground water must also be adequate to ensure that aquifers are not contaminated by leachate. Other requirements include a minimum depth of unconsolidated material overlying bedrock of at least 1.5 meters, no spreading on organic soils and the use of special conservation practices (including residue management) to help control runoff losses.

6.2 Other Potential Farm Pollution Hazards

Runoff from feed storage areas may contain high levels of carbon rich material which requires oxygen for decomposition (BOD). Most streams are unable to supply sufficient oxygen for BOD needs without seriously harming the aquatic organisms present. Corn silage can produce a highly acidic liquor with elevated nitrogen, phosphorus and BOD levels. It must be contained at the site to prevent contamination of surface water from overland flow and to prevent groundwater contamination from leaching. Therefore it is necessary to pave bunker silos and the area around upright silos and to construct berms to retain the runoff. Repavement of such areas may be necessary periodically to ensure their effectiveness, since soil-cement surfaces are not resistant to continous saturation with silage liquor which contains a variety of strong acids (McQuitty et al 1971). Proper storage facilities are also required to contain processing wastes (i.e. brewer's wastes and cannery wastes) used as feed sources. A lining or paved area beneath the storage area is necessary to prevent leaching and contamination of groundwater.

High volume milk-house wastes are difficult to treat effectively since they contain high BOD, phosphate and fat levels. It is important however that such liquids be kept out of water bodies. Milk house drains should be routed to ensure sufficient distance for complete attenuation of the waste before it empties into an open water course and new drains should be designed with this in mind. The addition of a retention pond, oxidation ditch and/or a vegetative filter system may also be advantageous in reducing the pollution potential.

Groundwater pollution has also occured from the burial of large numbers of animals. Consideration should be given to the local soil conditions, depth to groundwater, possibilities of leaching, and volume of animals before burial is chosen as a disposal method. If groundwater contamination is possible another method should be used.

Several miscellaneous procedures for water quality protection are summarized in Table 41.

Table 41. SUMMARY OF MISCELLANEOUS AGRICULTURAL PRACTICES FOR ENVIRONMENTAL PROTECTION

Practice	Where applicable	Advantages	Disadvantages
1. Use of sewage sludge	-where supply of suitable sludge available for land application -best with corn, grass hay, or commercial sod -when both site and sludge have met approved guidelines	-increased organic matter in soil -provides nutrients for plant growth	-improper use results in groundwater and runoff pollution -possible contamination of soil and plants with heavy metals and organics
2. Storage of animal feeds and processed wastes; milkhouse waste outlets	-when crop being ensilaged -where off farm processed waste brought to farm as source of animal feed -dairy farms	-containment of feed, milkhouse wastes and storage runoff protects groundwater and surface water from nutrients, high BOD, solids and toxic substances and toxic substances in feed	-cost of runoff containment and paving -upkeep of area due to strength of of silage liquor -construction of storage if off-farm processed waste used -cost of rerouting milkhouse drains; may require special structure (i.e. retention pond) for efficient operation
3. Disposal of dead animals	-livestock operations in areas of highly permeable soil and/or high water tables	-protects groundwater	-inconvenience and cost of alternative dead stock disposal

7. POSTSCRIPT

There is a great deal of information available on the effects of agricultural practices on water quality and on the effectiveness of various techniques to maintain and improve environmental quality. However this is scattered throughout many different journals and publications and an organized, comprehensive collection of information on techniques to reduce the potential for water pollution from agricultural land is not readily available. Furthermore techniques which have proven useful in studies done in the United States may not be suitable for Ontario farmers, or they may require modifications.

This publication has attempted to summarize the results of the studies most likely applicable to Ontario farms. Few of these practices are now widespread in Ontario, and there are few opportunities to judge the effectiveness of the various techniques in reducing water quality degradation or in their suitability for Ontario farm operations. There is a definite requirement for more research to document techniques and management practices suitable for the Ontario situation.

Research programs will have to be designed to investigate both the impact of new practices on the farming operation (e.g. yields, economic returns) and their effects on the environment. New ideas will require on-farm testing to determine their suitability and acceptability for Ontario's farmers. Information on why some practices are more readily accepted than others will be necessary to guide those who are promoting voluntary implementation of non-point pollution control programs. Individual farm management capabilities will be important in determining how well a practice will fit into an existing farm operation.

Farmers require advice and assistance in determining which alternatives might work on their farm. Increased co-ordination and dispersal of information from existing work in Ontario is necessary to promote practices which have proven beneficial to farmers in the Canadian Great Lakes Basin. Governments may be required to take a more active role to promote practices which are shown effective for reducing nonpoint pollution, but which have serious negative economic side-effects for the farmers. Non-point pollution control programs must be applied in a fair and equitable manner. This may require provision of expensive land and management alterations where it is warrented, while treating a similar problem with minor modifications under different circumstances.

A farmer makes many decisions every day which can greatly affect not only the amount of nonpoint pollution, but also the income derived from the farm. Given the potential for water pollution, it is clear that many farmers are already making an effort to practice good stewardship of the land and thus are individually protecting the environment. Good farming practices

must be promoted at every chance and farmers must have access to both the necessary information and financial backing to make sound land use decisions which are also economically viable. Today's farmers are resourceful and innovative. They are quite willing to adopt new practices to protect the environment. They are, however, operating complex businesses and must understand all the implications any new practice has for their farm. It is up to the agricultural research and extension community to help provide this information.

The techniques and practices outlined in this report are not all inclusive and innovations are constantly arising. Many farmers are aware of the environmental problems which can result from normal farming activities and are making an effort to reduce or eliminate such problems. Frequently they are uncertain as to what practices they should adopt and they often find it difficult to extract clear direction and advice specific to their needs from the wealth of knowledge which exists on the subject. It is hoped that this publication will provide farmers and people advising them with ideas which can be used or adapted to specific situations, to provide farmers with the guidance they need to maintain their productivity while they reduce the potential for water pollution from their farming operation.

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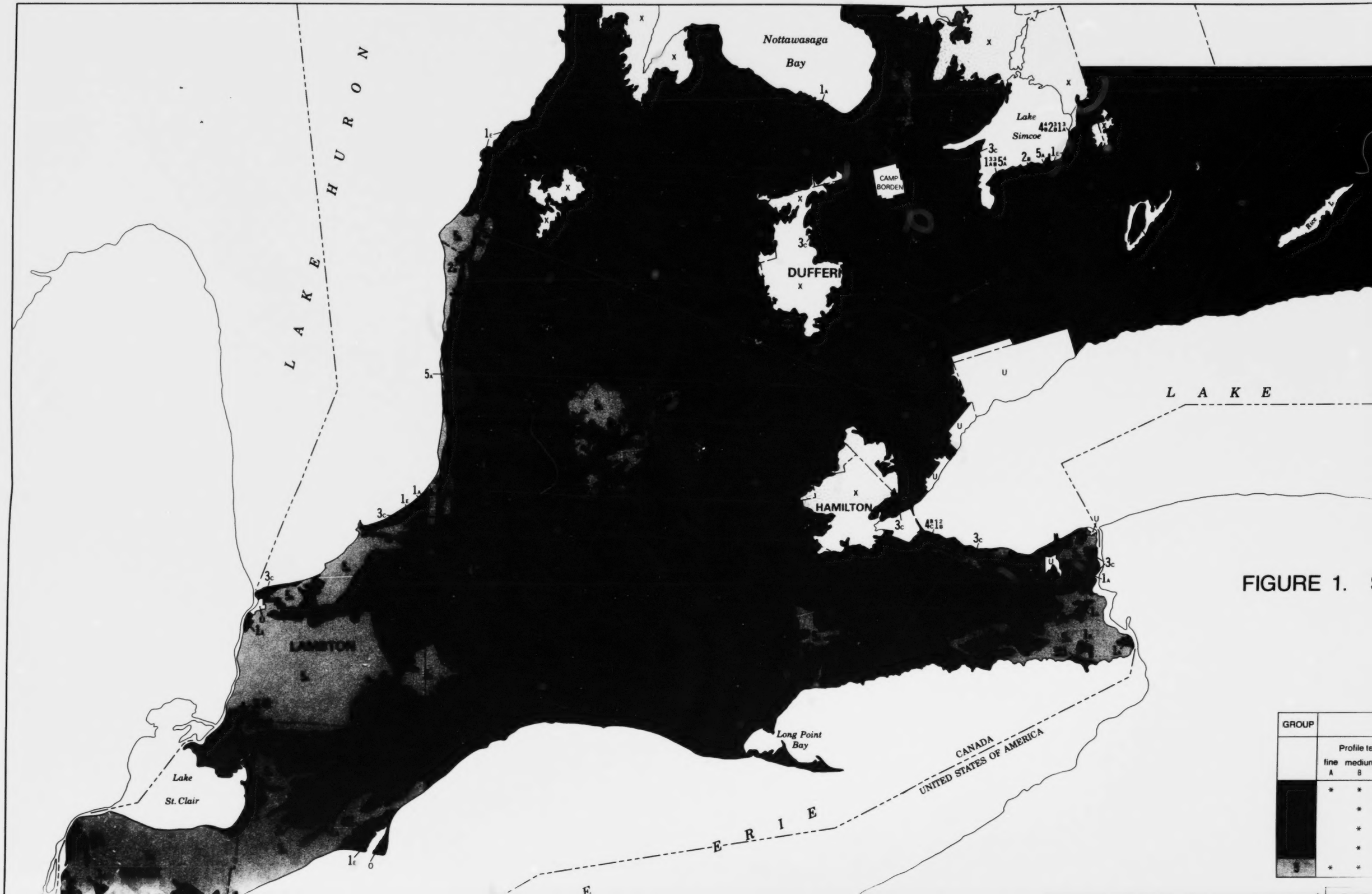

FIGURE 1.

GROUP	Profile te	
	fine A	medium B
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		*
	*	*

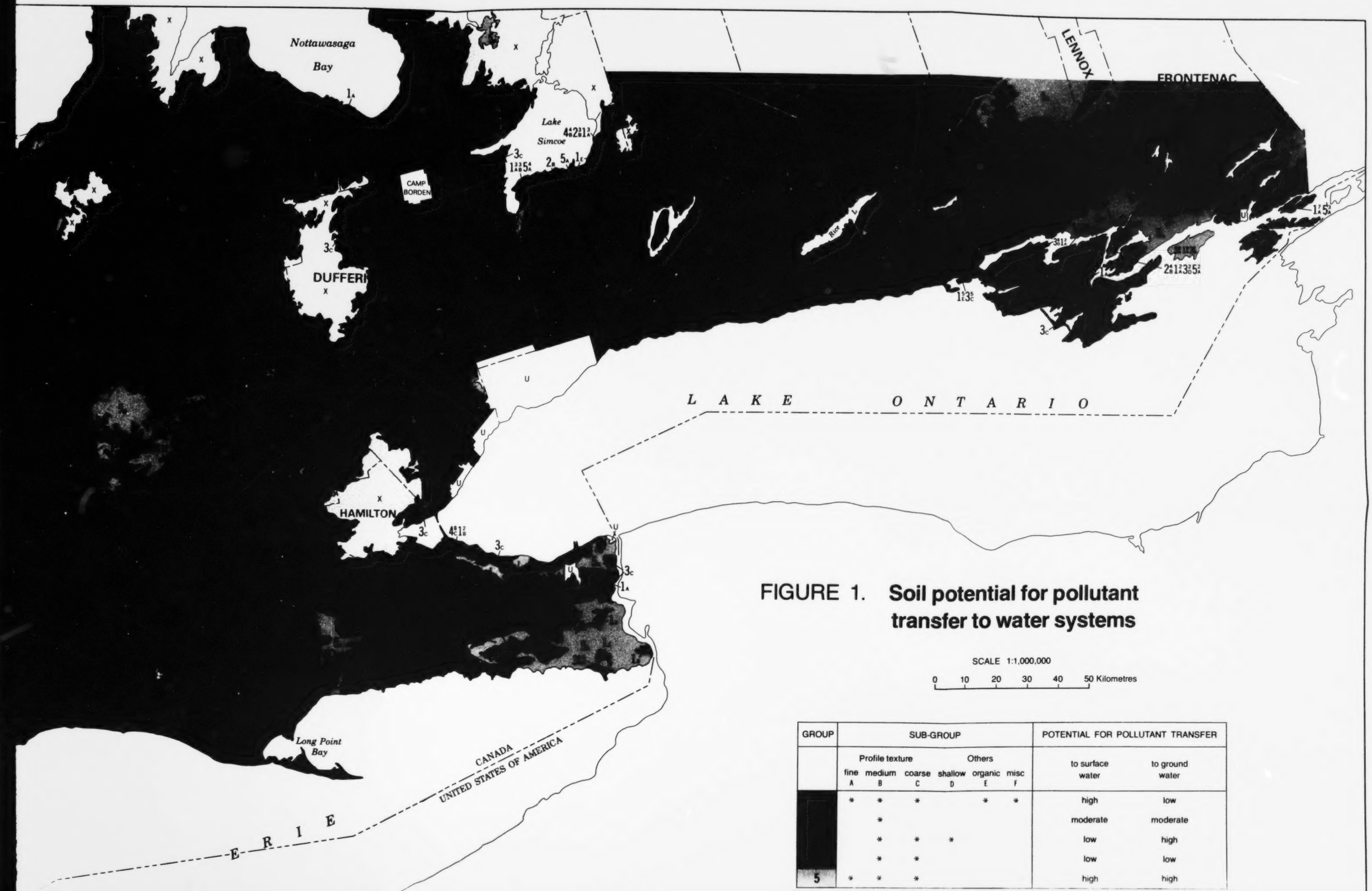

FIGURE 1. **Soil potential for pollutant transfer to water systems**

SCALE 1:1,000,000

0 10 20 30 40 50 Kilometres

GROUP	SUB-GROUP						POTENTIAL FOR POLLUTANT TRANSFER	
	Profile texture			Others			to surface water	to ground water
	fine A	medium B	coarse C	shallow D	organic E	misc F		
	*	*	*		*	*	high	low
		*					moderate	moderate
		*	*	*			low	high
		*	*				low	low
5	*	*	*				high	high

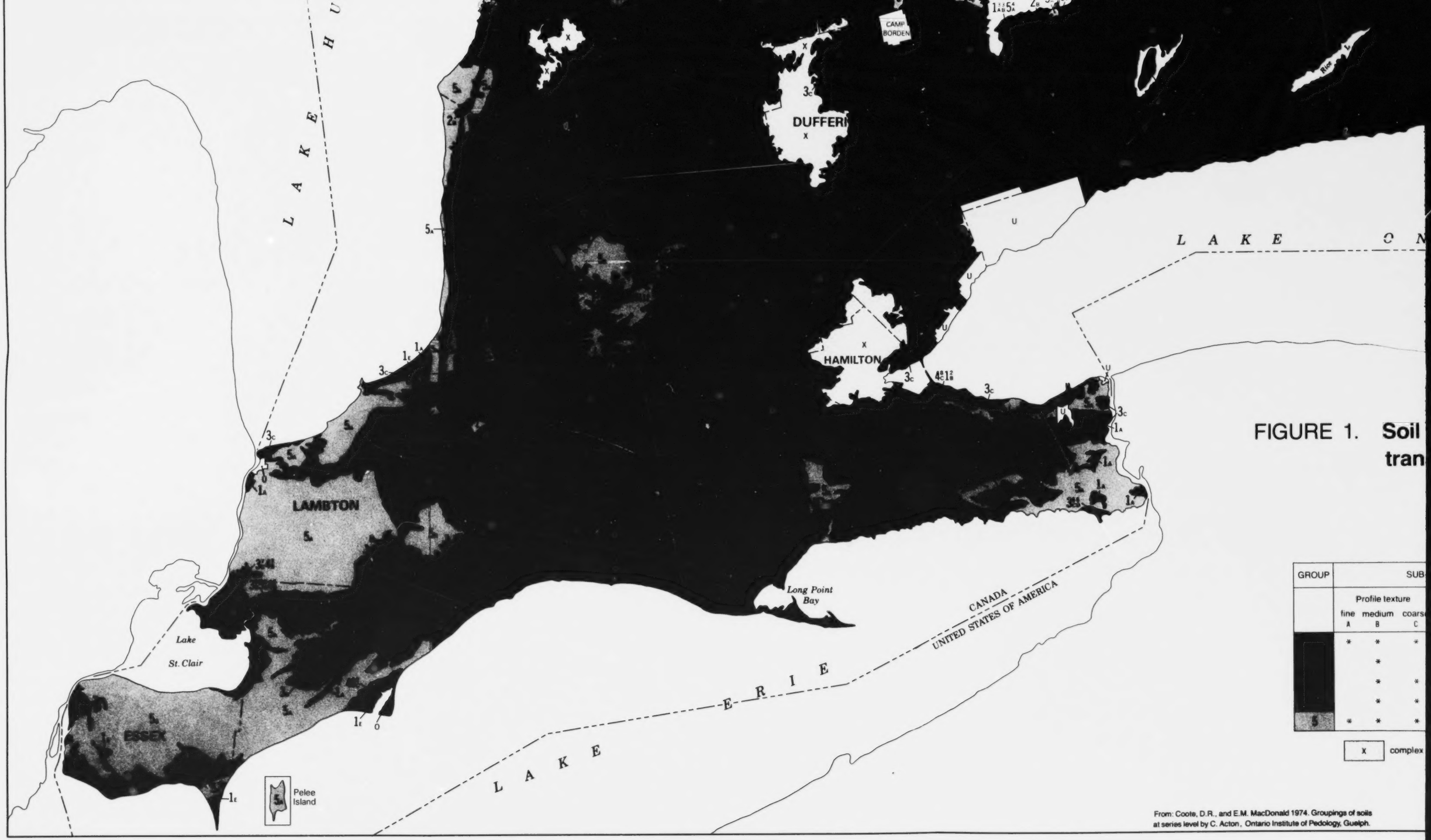

FIGURE 1. **Soil tran**

From: Coote, D.R., and E.M. MacDonald 1974. Groupings of soils at series level by C. Acton, Ontario Institute of Pedology, Guelph.

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	fine A	medium B	coarse C	shallow D	organic E	misc F		
	*	*	*		*	*	high	low
		*					moderate	moderate
		*	*	*			low	high
		*	*				low	low
	*	*	*				high	high

X complex — organic (undrained) — U urban

From: Coote, D.R., and E.M. MacDonald 1974. Groupings of soils at series level by C. Acton, Ontario Institute of Pedology, Guelph.

Redrafted by the Cartography Section, Land Resource Research Institute, Research Branch, Agriculture Canada, 1981. Printing for Agriculture Canada by the Map Reproduction Centre, Reproduction and Distribution Division, Energy, Mines and Resources, Ottawa.

FIGURE 1. So
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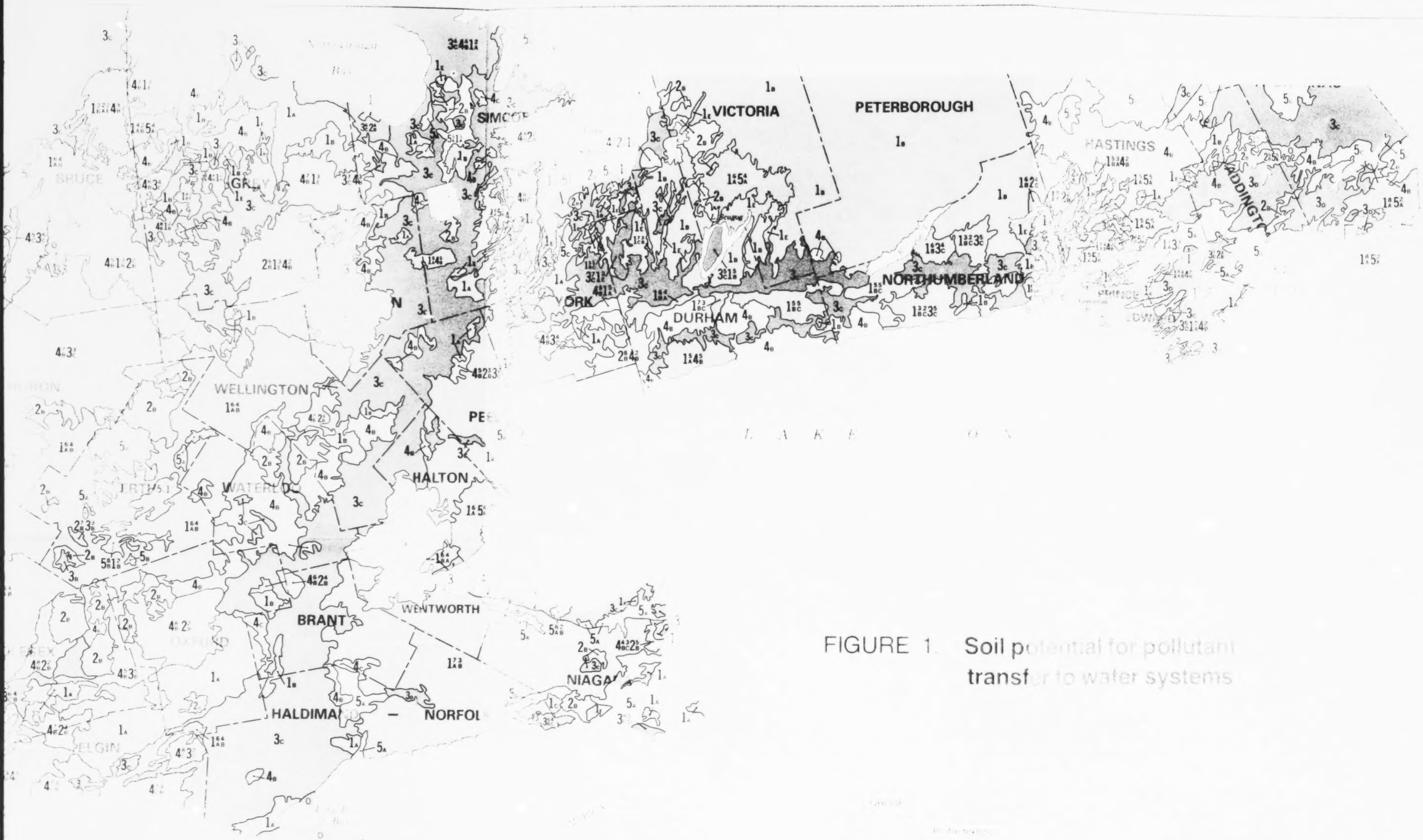

FIGURE 1. Soil potential for pollutant transfer to water systems

1
2
3
4

BRUCE
GREY
YORK
DURHAM
NORTHUMBERL
HURON
WELLINGTON
PEEL
HALTON
WATERLOO
PERTH
BRANT
WENTWORTH
OXFORD
MIDDLESEX
NIAGA
HALDIMA
NORFOLK
ELGIN
KENT

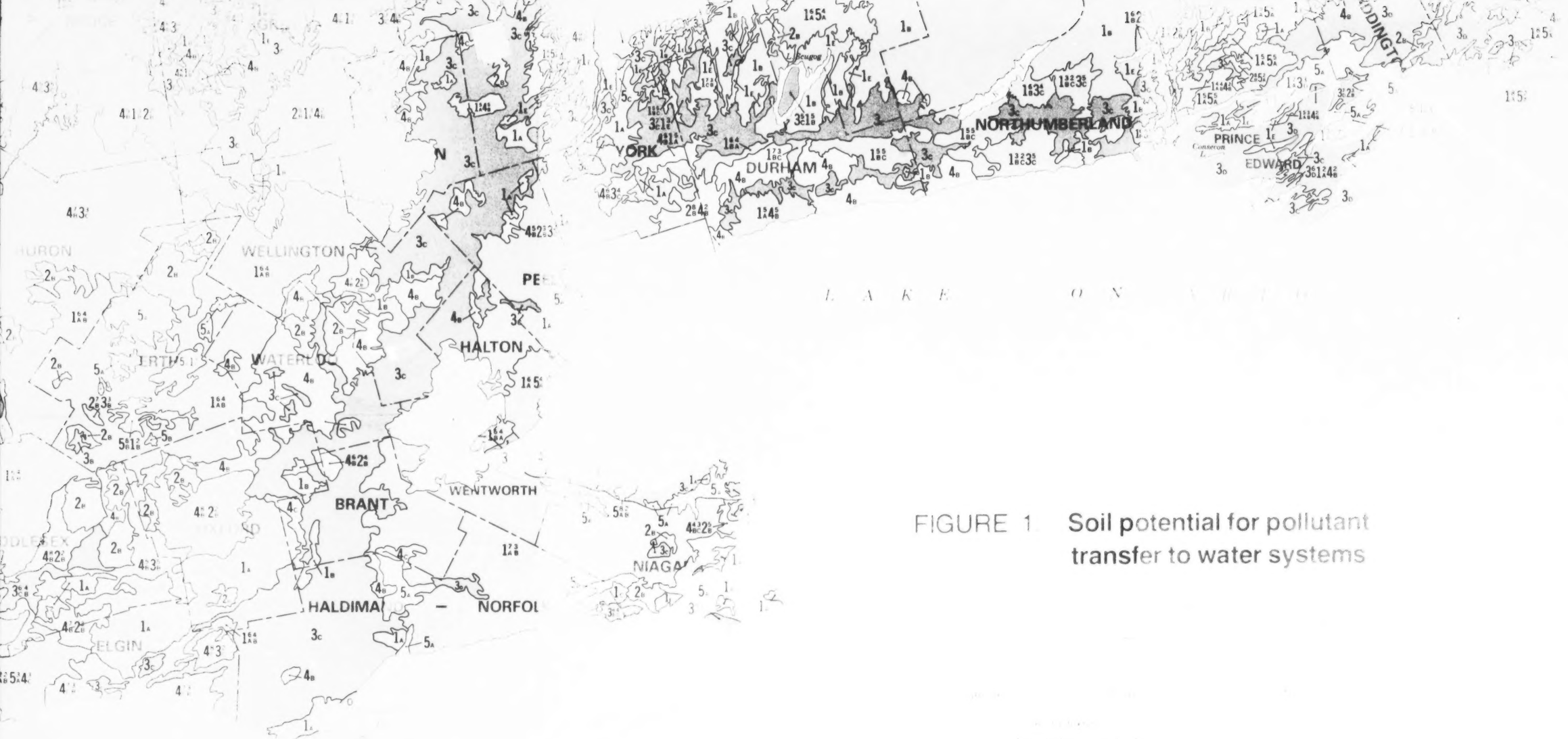

FIGURE 1 Soil potential for pollutant transfer to water systems

1
2
3
4
5

POOR

QUALITY

ORIGINAL